

Massachusetts Department of Transportation (MassDOT)

North South Rail Link Feasibility Reassessment

Final Report

January 2019



Massachusetts Department of Transportation (MassDOT)

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1. Introduction



1. Introduction

The North South Rail Link (NSRL) project would connect the Massachusetts Bay Transportation Authority's (MBTA) northside and southside commuter rail networks into one regional system through the construction and operation of a rail tunnel through Downtown Boston. This tunnel would enable through-running of MBTA Commuter Rail and Amtrak trains, increasing system coverage, capacity, and ridership.

1.1 Study Purpose

The Massachusetts Department of Transportation (MassDOT) commissioned Arup to conduct this NSRL Feasibility Reassessment, which reexamines prior work on the concept and was scoped to do the following:

- Identify significant changes to the context within which the NSRL would be implemented, such as demographic shifts, new transportation technologies, and trends and changes to the regulatory and built environments.
- Review the technical viability of major elements of the NSRL that were proposed by previous studies (two- versus four-track tunnels, two versus three stations in the tunnel section, service plan alternatives, the location and construction of tunnel portals, tunnel alignments, and station and headhouse locations). Consider new alternatives and develop these to a level of detail to allow for an assessment of costs and benefits.
- Develop an order-of-magnitude cost estimate (including design, construction, and management costs), assuming the initial use of dual-mode locomotives to avoid full electrification of the commuter rail system. This cost estimate will be informed by recent experience in rail tunnel construction (both international and domestic) and industry best practices.

- Consider overall project benefits including ridership growth, increased system capacity, service reliability improvements, and economic development, and quantify the benefits and associated costs at a level appropriate to this stage in the project development process.

The results of this Feasibility Reassessment will help inform MassDOT's and state policymakers' decisions about any appropriate next steps with regard to the NSRL concept.

An NSRL Working Group composed of assembled technical experts, provided independent review of project findings from this Feasibility Reassessment. They have been engaged at various points in the process and have provided feedback on project deliverables, including this report. The members of this group who regularly attended meetings with the project team are as follows:

- Lynn Ahlgren
- Brad Bellows
- Barry Bluestone
- Robert Culver
- Evan Efstathiou
- Ed Mueller
- Clay Schofield

1.2 Previous Studies

While a rail tunnel between North and South Stations had been considered since 1909, the modern concept of the NSRL was first introduced in 1972 as part of the Boston Transportation Planning Review's Central Artery report. This masterplan proposed a two-track rail tunnel alongside the Central Artery road tunnel, but the rail connection was eventually eliminated in order to secure federal funding for the highway project.

In 1993, the secretary of the Massachusetts Executive Office of Transportation and Construction (EOTC) convened the Central Artery Rail Link Task Force to study the feasibility of the rail tunnel using the Central Artery alignment. In its final report, the EOTC-appointed task force recommended the construction of the rail tunnel with first two tracks, and then four in a further phase, and three downtown stations (North Station, South Station, and State Street).

A number of studies developed by organizations outside of state government followed, proposing that a more thorough examination of engineering and environmental impact be conducted. To satisfy these requests for further study, the MBTA, Federal Transit Administration, the Massachusetts Highway Department, Amtrak, and EOTC partnered on a major investment study / draft environmental impact report (DEIR), released in June of 2003. The study identified a No Build scenario, one focusing

on enhancements to existing transit systems, and multiple variants of commuter rail tunnel build alternatives, accounting for different numbers of tracks, locations of south portals, numbers of stations, and alignments of the southern section of tunnel. All variants were evaluated in terms of financial feasibility, effectiveness, and equity measures:

- Two-track (Back Bay portal) / two-station
- Two-track (Back Bay portal) / three-station
- Two-track (South Bay portal) / two-station
- Two-track (South Bay portal) / three-station
- Four-track / two-station
- Four-track / three-station

The output of this evaluation was distributed to the relevant governmental agencies to inform decisions on future transportation investments. In addition to developing new alternatives, the current Feasibility Reassessment seeks to evaluate the 2003 rail concept in today's transportation context and provide updated estimates on anticipated benefits and costs.

1.3 Abbreviations

The following abbreviations are used throughout this report.

CTPS	Central Transportation Planning Staff
DEIR	Draft Environmental Impact Report
EOTC	Massachusetts Executive Office of Transportation and Construction
FTA	Federal Transit Administration
MAPC	Metropolitan Area Planning Council
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MBTA	Massachusetts Bay Transportation Authority
MPO	Metropolitan Planning Organization
NEC	Northeast Corridor
NSRL	North South Rail Link
SEM	Sequential Excavation Method
SSX	South Station Expansion
TAZ	Traffic Analysis Zones
TBM	Tunnel Boring Machine

2. Problem Statement



Photo Source: Osman Rana

2. Problem Statement

The NSRL has the potential to address several separate but interrelated needs in Boston's travel market.

2.1 A Growing Region

The Greater Boston area continues to add both jobs and people, straining its existing transportation network. A number of traffic indices rank the Boston metropolitan area, alongside Los Angeles, New York, San Francisco, and Washington DC, as among the most congested in the US,¹ and in the past 16 years, the City of Boston has experienced 8% population growth and 4% employment growth, while in the region's MBTA service area, population grew by 5% and employment by 10%, exacerbating capacity constraints in the transit system.² Similar to other growing regions, the Greater Boston economy has grown faster than its transportation infrastructure.



Traffic congestion



Crowds at MBTA Park Street Station

2.2 A Divided System

The MBTA's Commuter Rail network operates as essentially two separate systems, with five lines serving the areas north of the urban core and terminating at North Station, and the remaining nine lines serving areas south (and, to a lesser extent, west) of the urban core and terminating at South Station. This division creates two separate markets: lines running into South Station have easy access to the Back Bay, the Financial District and the Seaport District, while lines running into North Station arrive at the northern end of downtown, an area with lower employment density and fewer major destinations. This division creates disincentives for commuters from the northern suburbs to use transit to reach jobs in Downtown Boston and Back Bay, as many trips require a transfer from commuter rail to subway, adding about 10 minutes to their overall journey. Meanwhile, suburb-to-suburb trips between commuter-rail-accessible areas south and north of Boston's urban core require multiple transfers, and those trips are currently unlikely to be completed via public transit. This is supported by an analysis of 2010 journey-to-work data for this project, which shows the majority of trips from either the northside or southside MBTA Commuter Rail lines ending in a Downtown Boston destination.

2.3 Operational Issues

Operationally, this divided system creates inefficient terminals, limiting the number of trains that can enter and exit downtown during peak periods. Both North Station and South Station are stub-end terminals requiring trains to reverse direction to continue in both revenue and non-revenue service. Train schedules must allow adequate time for turning around and checking equipment, meaning trains occupy available tracks and platforms and thus reduce the overall number of trains that can serve the terminals at peak periods.

The division of the system also results in commuter rail fleet inefficiencies, as trains cannot easily move between the northern and southern portions of the commuter rail system. Storage and maintenance occurs within the separate portions of the system, in order to avoid these costly and slow train movements on the few and inadequate links between north and south.

The lack of direct connections between North Station trains and Back Bay or downtown core destinations contributes to overcrowding on the MBTA rapid transit system at peak times, as many North Station commuter rail passengers transfer to the Orange and Green Lines to complete their trips.

3. Background Information



3. Background Information

The NSRL Feasibility Reassessment considers an economic and policy environment that has evolved and changed over the last 15 years. These changes range from demographic shifts — where and how people live and work — to physical changes including transformational modifications and improvements to the transportation system. To provide a disciplined assessment of the current potential for the NSRL, a set of guiding principles were developed for the study. Peer projects from around the world were investigated to understand best practices and value opportunities, and to provide thorough analysis and comparison.

3.1 Existing Conditions

Overview of the Region

Boston is the economic center of New England, and the central city of the 10th-largest metropolitan statistical area in the United States. Its concentration of highly skilled workers, high median household incomes, and strong healthcare, educational, and technology sectors all make Boston an important part of the larger Northeast Corridor (NEC) megaregion.³

A robust transportation system — comprising an interconnected highway network, intercity rail, and an international airport — provides key connections to the rest of the NEC and the country. However, local networks can be congested, due to growing demand, aging infrastructure and its attendant reliability issues, and transit capacity constraints at various points in the network. Additionally, indirect connections between locations can make journeys long and inconvenient.⁴

The urban core holds the majority of jobs, attracting hundreds of thousands of trips every day. However, while this area has seen the majority of growth in recent years, both jobs and people are spread widely throughout the region, leaving many trips dependent on private automobiles.

Overview of the Study Area

Although the NSRL's connections would improve transit trips for users throughout the region's transportation system, the project's construction impacts are concentrated on the central areas of Boston.

The project provides either a two- or four-track rail tunnel connecting North and South Stations, and entrance portals on both the north and south ends that connect to the wider commuter rail network. Tunnel alignment alternatives for this Feasibility Reassessment take account of the substantial development that has occurred along the Central Artery and in the surrounding neighborhoods that might have an impact on where tunnels can be located. Figures 1 and 2 illustrate these recent developments and the development that is planned within and along the indicative area encompassing potential tunnel alignments. This information was collected from the MassBuilds development database, administered by the Metropolitan Area Planning Council, which has been collecting data on constructed and planned developments throughout the Greater Boston area dating back to 2010.⁵

Rank	Metro Area	Population (Thousands)			Percent Change	
		2000	2016	Change	Total	Avg. Annual
1	Phoenix	3,252	4,662	1,410	43.3%	2.3%
2	Houston	4,878	6,973	2,095	42.9%	2.3%
3	Dallas	5,596	7,673	2,076	37.1%	2.0%
4	Atlanta	4,779	6,453	1,674	35.0%	1.9%
5	Seattle	3,776	4,685	909	24.1%	1.4%
6	Miami	5,476	6,725	1,249	22.8%	1.3%
7	DC	7,981	9,671	1,690	21.2%	1.2%
8	San Francisco	7,656	8,752	1,096	14.3%	0.8%
9	Los Angeles	16,374	18,688	2,314	14.1%	0.8%
10	Philadelphia	6,689	7,179	491	7.3%	0.4%
11	Boston	7,630	8,176	546	7.2%	0.4%
12	New York	22,241	23,689	1,448	6.5%	0.4%
13	Chicago	9,465	9,883	417	4.4%	0.3%

Table 1: Metro Area Rankings by Population Growth Rate

2000 – 2016

Source: US Census Bureau, Decennial Census 2000, American Community Survey 2016 1-Year Estimates

Rank	Metro Area	Population (Thousands)			Percent Change	
		2000	2016	Change	Total	Avg. Annual
1	Los Angeles	16,374	18,688	2,314	14.1%	0.8%
2	Houston	4,878	6,973	2,095	42.9%	2.3%
3	Dallas	5,596	7,673	2,076	37.1%	2.0%
4	DC	7,981	9,671	1,690	21.2%	1.2%
5	Atlanta	4,779	6,453	1,674	35.0%	1.9%
6	New York	22,241	23,689	1,448	6.5%	0.4%
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Table 2: Metro Area Rankings by Population Growth (Absolute)

2000 - 2016

Rank	Metro Area	Employment (Thousands)			Percent Change	
		2000	2016	Change	Total	Avg. Annual
1	Houston	2,272	2,947	675	29.7%	1.6%
2	Dallas	2,852	3,496	644	22.6%	1.3%
3	Phoenix	1,584	1,933	349	22.0%	1.3%
4	Miami	2,255	2,675	420	18.6%	1.1%
5	Seattle	1,864	2,195	331	17.7%	1.0%
6	Atlanta	2,413	2,765	352	14.6%	0.9%
7	DC	4,097	4,679	582	14.2%	0.8%
8	Los Angeles	6,794	7,619	825	12.1%	0.7%
9	New York	9,791	10,629	838	8.6%	0.5%
10	San Francisco	3,863	4,139	275	7.1%	0.4%
11	Boston	3,835	4,067	232	6.1%	0.4%
12	Philadelphia	3,069	3,182	113	3.7%	0.2%
13	Chicago	4,534	4,591	57	1.3%	0.1%

Table 3: Metro Area Rankings by Employment Growth Rate

2000 - 2016

Source: Bureau of Labor Statistics, Quarterly Census of Employment and Wages, Annual Averages

Rank	Metro Area	Employment (Thousands)			Percent Change	
		2000	2016	Change	Total	Avg. Annual
1	New York	9,791	10,629	838	8.6%	0.5%
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Table 4: Metro Area Rankings by Employment Growth (Absolute)

2000 - 2016

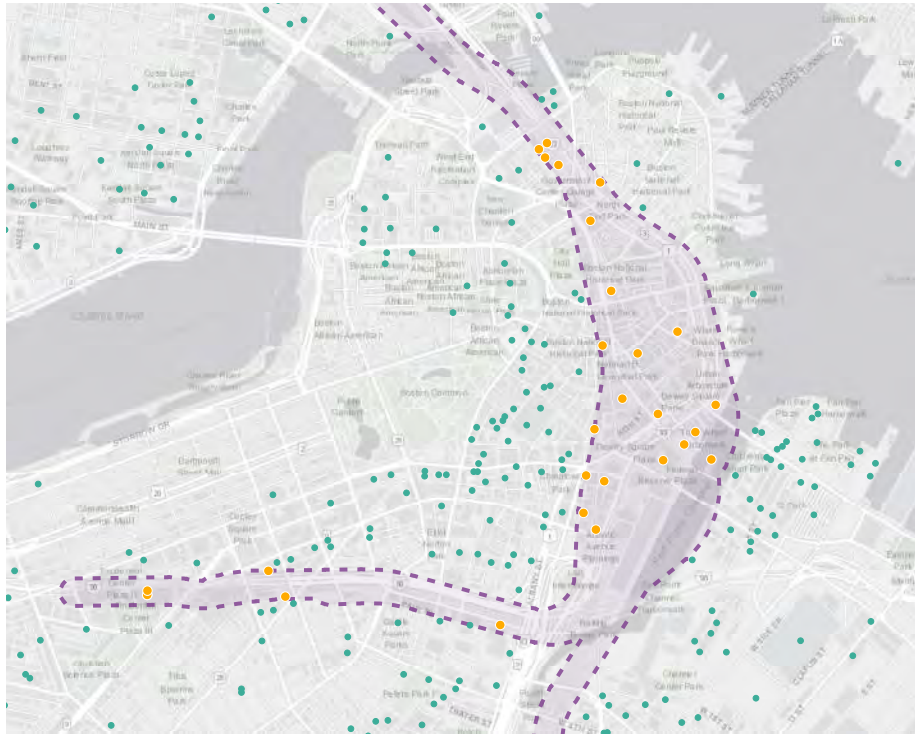


Figure 1: Properties Constructed or Renovated
2000 – 2017

- All Developments 2000–2017 within 200 Feet of Alignment
- All Developments
- Indicative Alignment Area

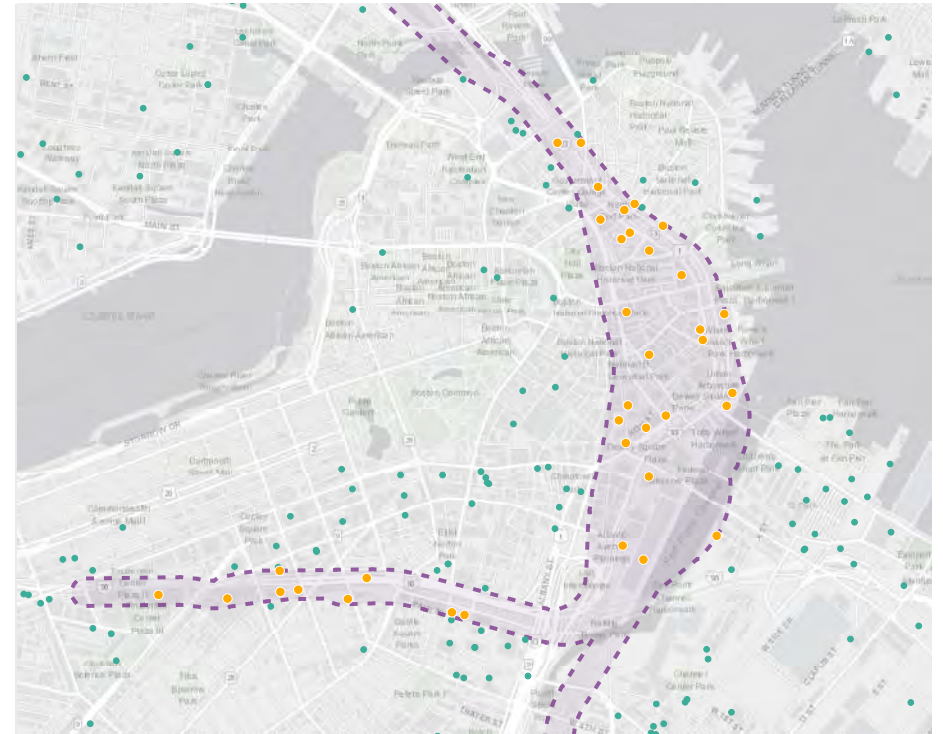


Figure 2: Planned Developments
2018+

- All Developments 2018+ within 200 Feet of Alignment
- All Developments
- Indicative Alignment Area



Boston Metro Transit System

While the majority of the region's commuters drive to work, approximately 13% utilize the region's extensive transit system for work trips. This system is operated by the MBTA, an authority created by the General Court in 1964. It is one of the first combined regional transit system to be established in the United States.⁶ The MBTA is overseen by two governing bodies: the MassDOT Board and the Fiscal and Management Control Board, the latter established in July of 2015 to monitor finances, management, and operations.⁷ The MBTA operates as a division of MassDOT, under its Rail & Transit Division.⁸

The MBTA transports more than 1.3 million passengers daily via a variety of modes, making it the fifth-largest mass transit system in the United States. It operates 175 bus routes, two light rail lines (the Green Line and the Mattapan High Speed Line, an extension of the Red Line from Ashmont to Mattapan), three heavy-rail subway lines (the Red, Blue, and Orange Lines), and 14 commuter rail lines. The MBTA also provides ferry and paratransit services.⁹

The MBTA service area is comprised of 175 municipalities,¹⁰ classified into the following three categories:

- **Core Service Area**
The urban core. Includes Boston, Arlington, Belmont, Brookline, Cambridge, Chelsea, Everett, Malden, Medford, Melrose, Newton, Quincy, Revere, Somerville, Waltham, Watertown, and Winthrop.
- **Gateway Cities**
Midsize post-industrial cities in the MBTA service area outside of the Core Service Area. Includes Brockton, Fitchburg, Framingham, Haverhill, Lawrence, Leominster, Lowell, Lynn, Salem, and Worcester.
- **Other MBTA Service Area**
The rest of the municipalities comprising the MBTA assessment district.¹¹

Figure 3 shows the geographies as they relate to the commuter rail network. These geographies have been used for the demographic analyses in Section 3.2 to help understand the geographic distribution of various trends.



MBTA signage

The MBTA Commuter Rail System

The MBTA's Commuter Rail system is comprised of 14 routes serving 138 stations over 388 route miles, all connecting to Downtown Boston.¹² The five routes running into North Station are Newburyport, Rockport, Haverhill, Lowell, and Fitchburg. The nine routes running into South Station are Framingham/Worcester, Needham, Franklin, Providence, Stoughton, Fairmount, Middleborough/Lakeville, Kingston/Plymouth, and Greenbush. Figure 4 illustrates the commuter rail system, as well as the rapid transit lines and the Silver Line.

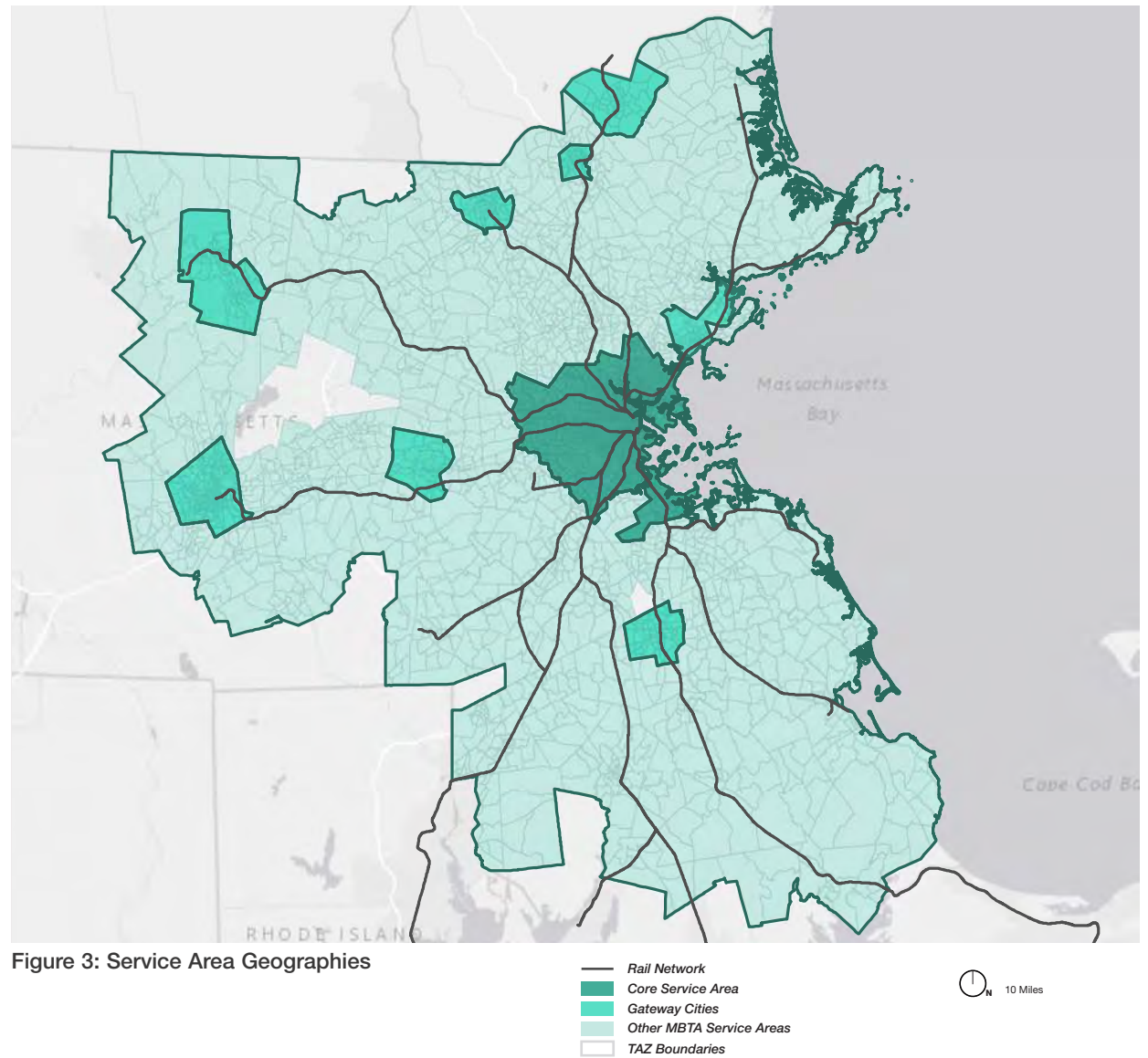




Figure 4: Map of MBTA Commuter Rail System

Operations

The commuter rail system is operated and maintained by Keolis, a third-party contractor. Keolis is also responsible for the maintenance of the MBTA's approximately 90 diesel locomotives and more than 400 coaches, both single- and double-decker.¹³

While the span of service stretches from 3:30am to 1:40am on weekdays and 6:30am to 11:30pm on weekends, the most frequent service is provided for peak-period, peak-direction travel into and out of Downtown Boston. Midday and off-peak service is limited, making the commuter rail service most useful for those with regular work commuting patterns.

Lengthy sections of single-track and busy shared facilities — such as Reading Junction (the point where the Haverhill, Newburyport, and Rockport Lines merge), and the congested NEC network serving five commuter rail routes and Amtrak — create capacity and service constraints.

Maintenance facilities and yards are limited on either side of the network, and standard operating conditions such as restrictions on how closely trains can pass through signals and junctions can limit the throughput of more trains. In recent years, however, reliability has improved — in 2017, commuter rail had on-time performance of 93% and 99.6% of scheduled service was operated.¹⁴

Ridership

Average weekday ridership for MBTA commuter rail, taken from the National Transit Database, was 131,160 in 2012. The Boston Region Metropolitan Planning Organization (MPO)'s Central Transportation Planning Staff (CTPS) conducted a comprehensive survey of ridership by commuter rail line in 2012, which included manual passenger counts between January and June of that year. The survey collected detailed information that shows boardings and alightings for each route, as well as passenger loads on particular segments of the lines. Estimates were also made for station-to-station ridership and the proportion of interzone ridership. The results of this 2012 survey are summarized in Table 5.

A separate MBTA report on the state of the commuter rail system noted that '98% of commuter rail trains had a seat for every passenger', indicating that very few of these lines are experiencing trains that are running over capacity.¹⁵



MBTA Commuter Rail Maintenance Facility

Commuter Rail Line		Daily Inbound Riders	Daily Outbound Riders	Total Daily Riders	Daily Inbound Trains	Daily Outbound Trains	Total Daily Trains
North Side Lines	Newburyport/Rockport	6,958	7,045	14,003	30	30	60
	Haverhill	3,489	3,502	6,991	24	24	48
	Lowell	4,988	4,639	9,627	31	27	58
	Fitchburg	3,955	3,969	7,924	17	17	34
	Worcester/Framingham	6,451	6,336	12,787	21	20	41
South Side Lines	Needham	2,724	3,090	5,814	16	16	32
	Franklin	4,959	5,121	10,080	19	18	37
	Providence/Stoughton	10,887	10,610	21,497	35	37	72
	Fairmount	376	413	789	17	15	32
	Middleborough/Lakeville	2,461	2,545	5,006	12	12	24
	Kingston/Plymouth	2,802	2,711	5,513	12	12	24
	Greenbush	2,191	2,162	4,353	12	12	24

Table 5: MBTA Commuter Rail Weekday Passenger Counts by Line

2012

These numbers show that ridership is skewed toward the lines leading to South Station, which carry about 66,000 passengers (63%) both inbound and outbound on a typical weekday, as compared to the lines running into North Station, which carry about 38,500 passengers (37%). This split is roughly in line with DEIR observations from 2003.¹⁶

Trends in ridership can be inferred by examining historical data, available from 2000 onwards. As illustrated in Figure 5, MBTA ridership has been declining since 2009, when it was at a high of almost 147,000. A number of factors may have had an impact on this approximate 15% decrease in commuter rail ridership. Possible explanations include four fare increases since 2003 (in 2005, 2008, 2012, and 2014), lower gas prices from 2008 to 2010 and then since 2014, the impacts of severe weather in the winter of 2015, and more people living in the urban core. In addition to this, the difficulty of accurately forecasting into the future is readily acknowledged amongst the planning community.

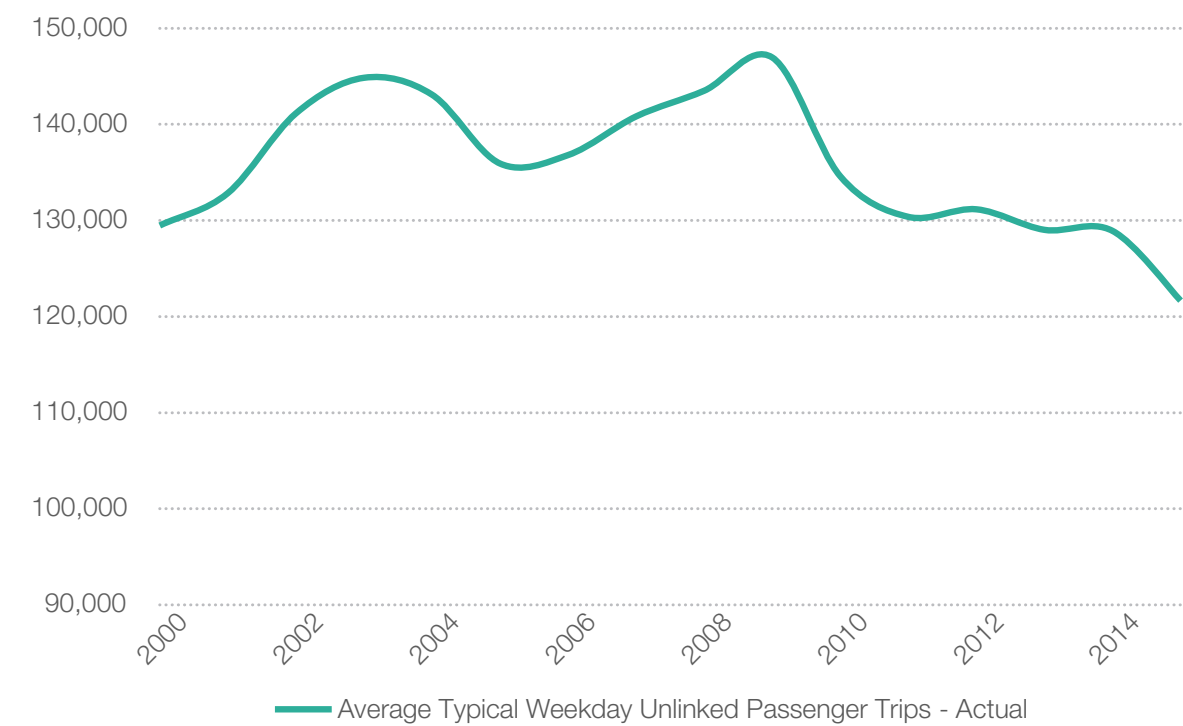


Figure 5: MBTA Commuter Rail Average Weekday Ridership
2000–2015 (Source: National Transit Database)

Amtrak

Amtrak currently runs four services into Boston terminals:

- Acela and NEC services running from Washington DC / Virginia to South Station (19 daily trains arriving and 20 departing)
- Lake Shore Limited service running out of South Station to Chicago via Springfield, Massachusetts (one daily train in either direction)
- Downeaster service from Maine to North Station (five daily trains in either direction).

Table 6 approximates ridership on the NEC/Acela and Downeaster services, using Amtrak's station counts showing average weekday ons and offs at Back Bay, South, and North Stations. This method was considered more accurate than full NEC ridership data, as these numbers include the full extent of routes running down to Washington DC and Virginia. Figures from 2012 are used to provide a direct comparison to the MBTA ridership discussed above.



Amtrak train at South Station

Photo Source: MTA / Flickr

Figure 6 shows historical average weekday ridership counts for Amtrak at Back Bay, South, and North Stations. Amtrak ridership figures, as opposed to commuter rail ridership, show steady growth at all Boston stations from 2001 to 2016, more than doubling over this period.

	Average Weekday Ridership (2012)
Amtrak Northeast Corridor incl. Acela (Back Bay and South Stations)	5,660
Amtrak Downeaster (North Station)	1,340
Total	7,000

Table 6: 2012 Weekday Ridership Data

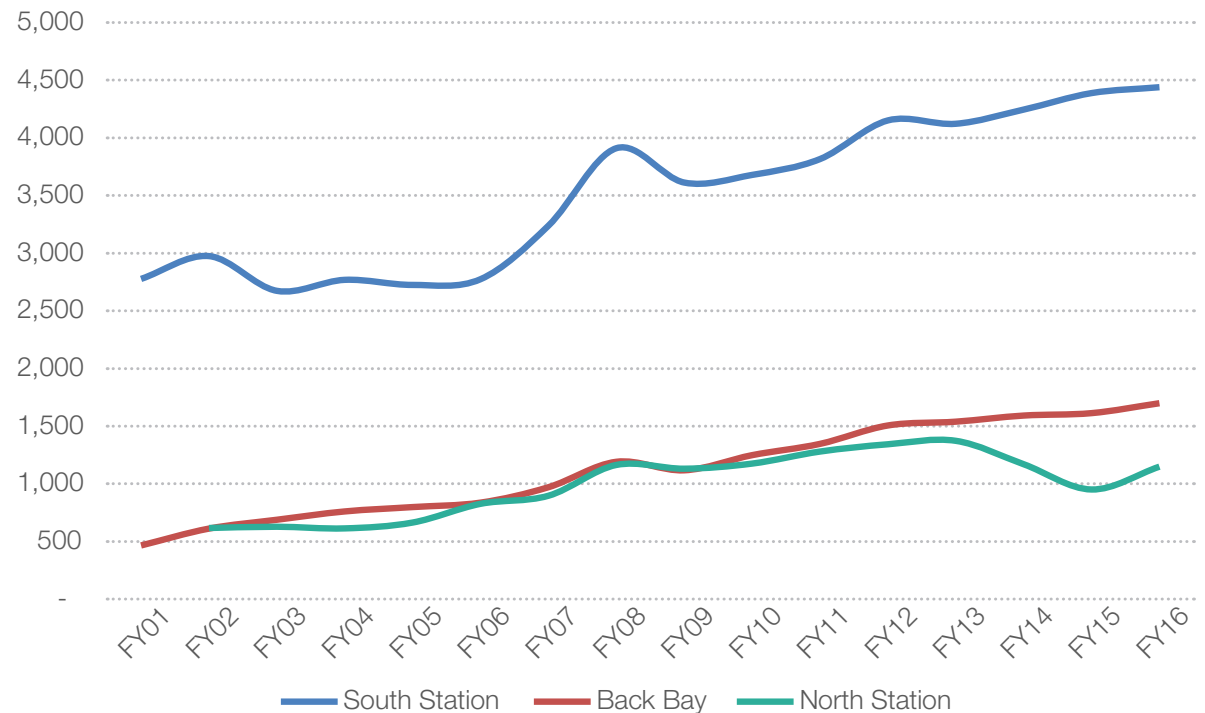


Figure 6: Amtrak Average Weekday Ridership

2001 – 2016 (Source: Amtrak)

3.2 Regional Demographics

Demographic changes in the MBTA service area are a key component of this Feasibility Reassessment. Projections used by CTPS and developed by the Metropolitan Area Planning Council serve as the basis for characterizing changes in regional growth, demographics, and development patterns in order to better understand the market for the NSRL. For all of the following analyses, population and employment data from 2000 (which was used in the 2003 report) were compared to 2016 figures used by CTPS. Regional demographic data includes population by age, households by type (by worker, by household income, and by auto availability), and employment categories (basic, retail, and service).

Population and household data came from the US Census, while employment data are from InfoUSA (a private data vendor). Vehicle ownership information was collected separately from the US Census for 2000 and 2015. These data, compared at a municipal level, informed the context review analysis for the NSRL project, and resulted in the maps and analysis provided over the next few pages.

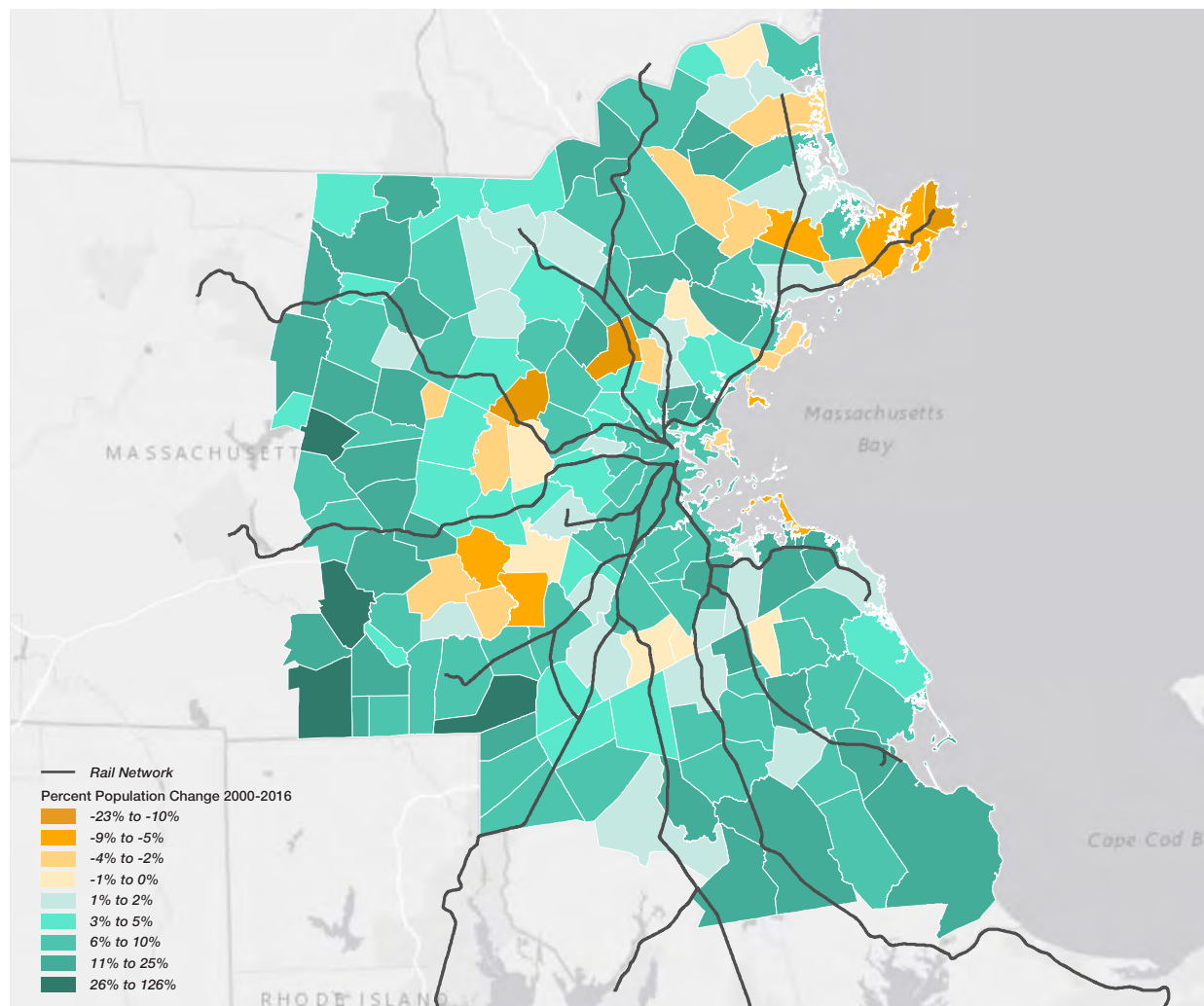


Figure 7: Population Change in the Study Area

2000—2016 – Percentage Change



The study area’s population grew from 4.3 million in 2000 to 4.6 million in 2016, at an annual rate of approximately 0.4%.

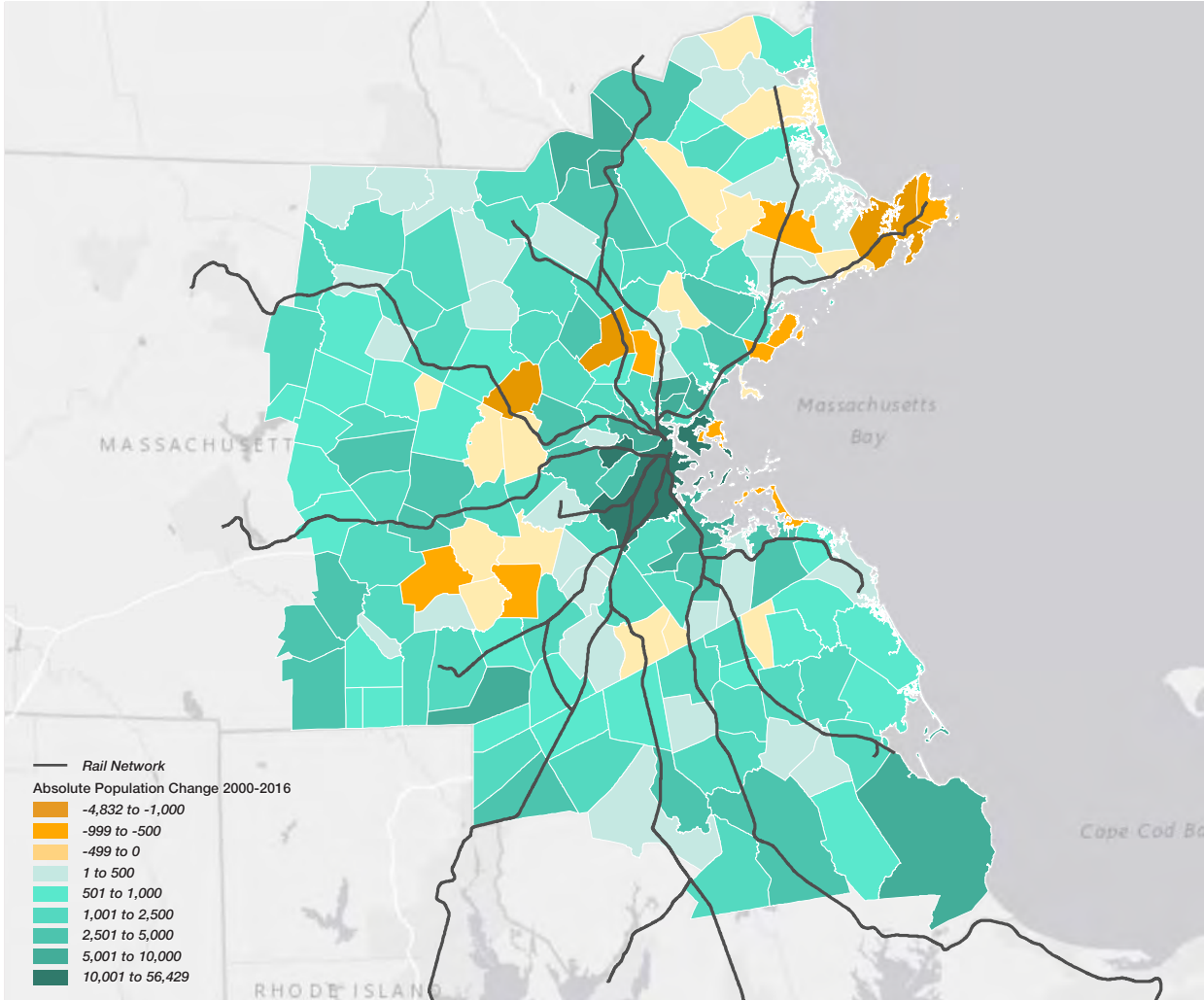


Figure 8: Population Change in the Study Area
2000—2016 – Absolute Change



Employment grew from 2.3 million in 2000 to 2.5 million in 2016, at an annual rate of approximately 0.5%. Figure 9 shows the distribution of this growth as a percentage.

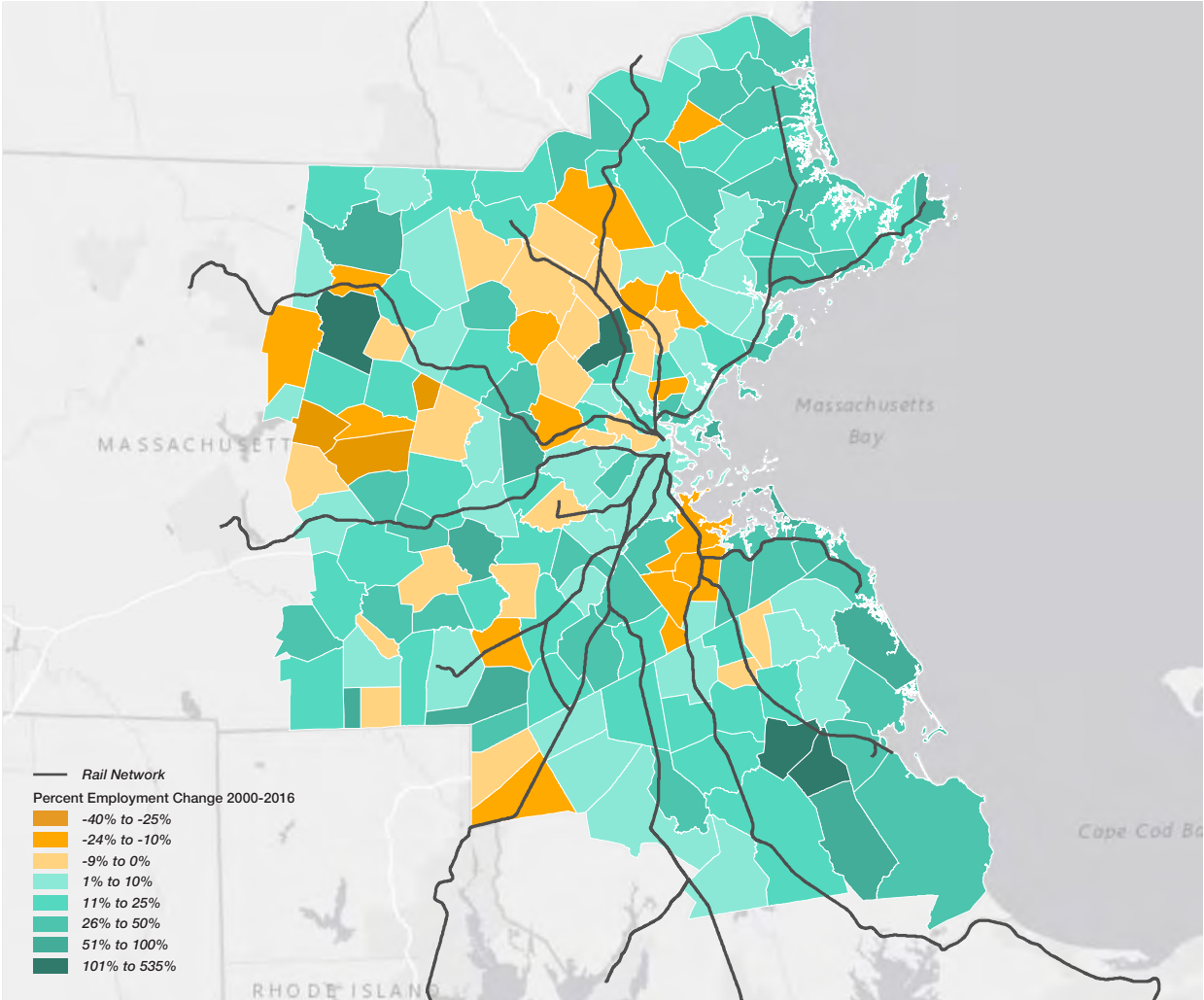


Figure 9: Employment Change in the Study Area
2000—2016 – Percentage Change

Figure 10 shows the distribution of this growth in absolute numbers.

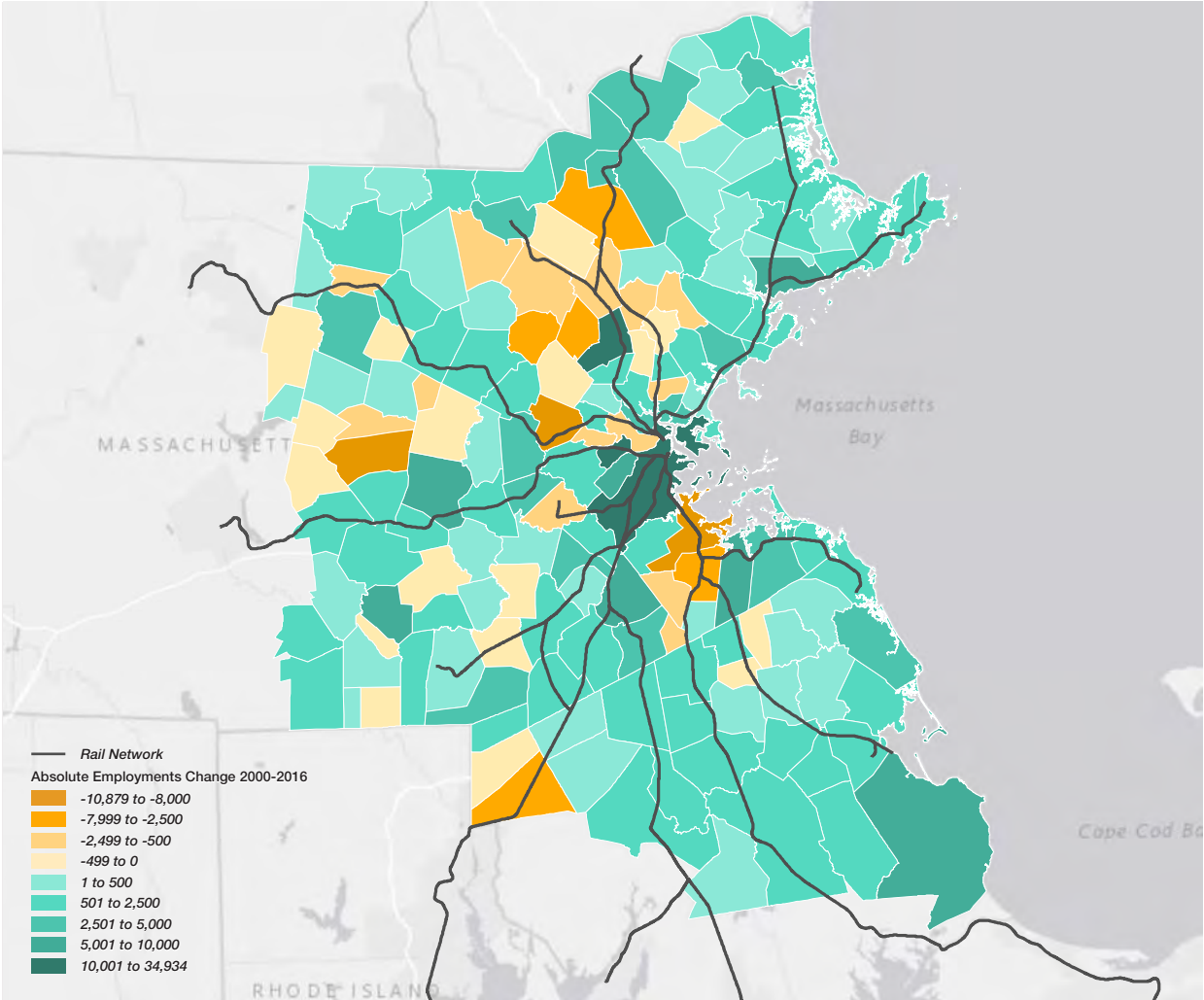


Figure 10: Employment Change in the Study Area
2000—2016 – Absolute Change



A closer look at growth in each of the geographies helps to shed light on the spatial distribution of population growth in the study area. Between 2000 and 2016, population growth concentrated in the Core Service Area, which grew at a faster rate (8%) than the Gateway Cities and the Other MBTA Service Area, each of which grew at approximately the same rate (5%). The few municipalities inside the study area but not designated within the categorized geographies saw a high growth rate, but account for a small portion of all residents.

Between 2000 and 2016, about 60% of employment growth in the study area occurred outside Core Service and Gateway Cities, indicating that growth is not tightly concentrated in one area. The rate of employment growth was lowest in the Core Service Area (which started with a large number of jobs), and the Gateway Cities greatly outpaced the other two geographic areas in the rate of its job growth. Figures 11 and 12 show the trend lines for each geography.

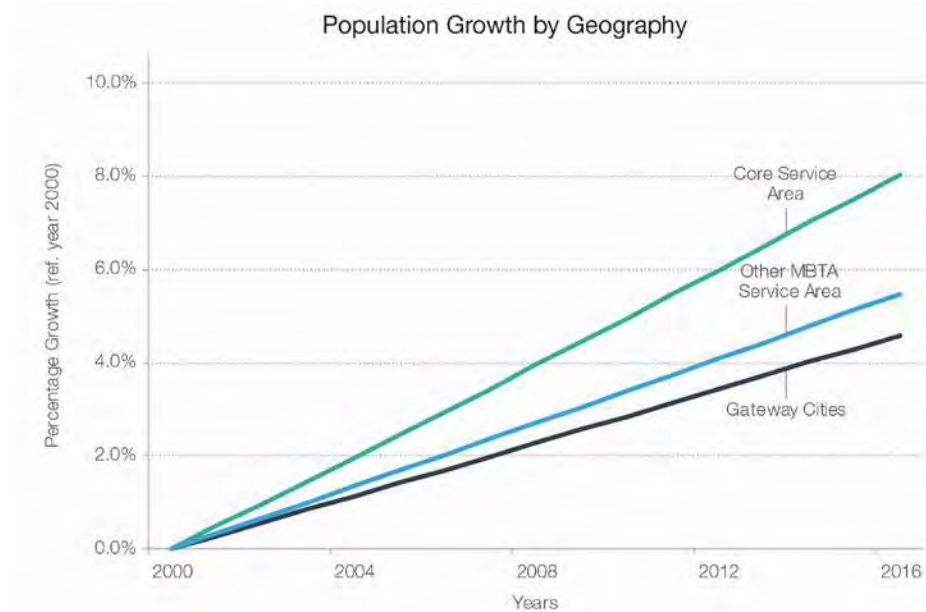


Figure 11: Population Change by Geography

2000–2016

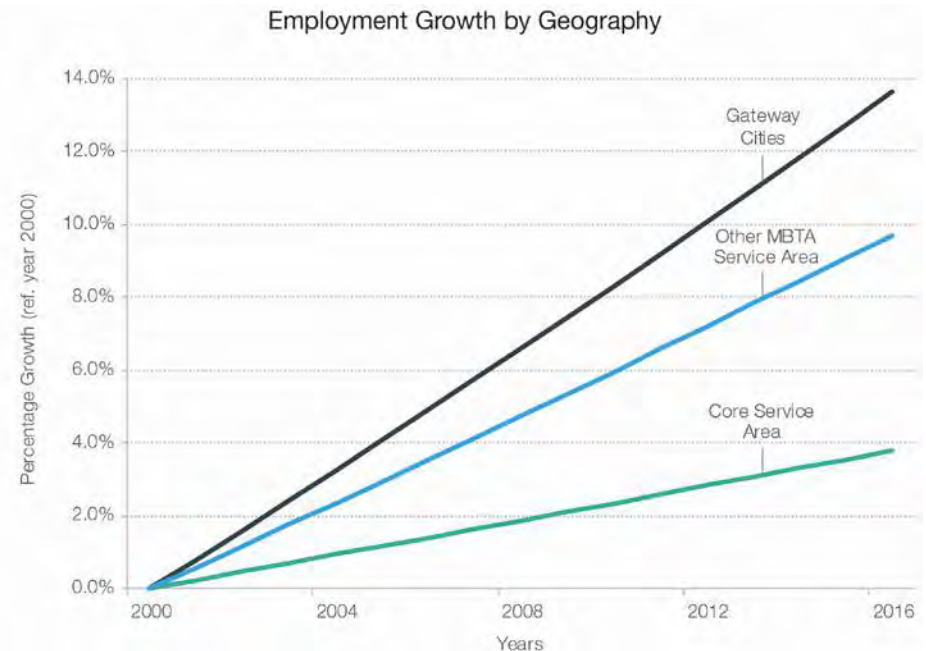


Figure 12: Employment Change by Geography

2000–2016

Auto Ownership and Land Use

Certain indicators, such as auto ownership by household and changes in land use, can be used to identify potential markets for transit.

Census data show low household vehicle ownership in the region, and this indicator has remained fairly constant since the DEIR examined data from 2000. The proportion of zero-vehicle households throughout the study area did not change significantly over the period; however, the proportion of households with access to one or two cars decreased slightly, while those with access to three or four (or more) cars increased slightly. Overall, the average rate of household vehicle ownership increased by 2.3% (or about four additional cars per hundred households) for the region as a whole. It is unlikely that this trend will have a major impact on travel throughout the study area.

Figure 13 shows the geographic distribution of vehicles per household in 2015 — unsurprisingly, the areas in the MBTA Core Service Area, well served by transit, have the lowest number of household vehicles, while the greatest numbers are seen in areas farther out from the city center. However, numbers remain low in some of these far-flung municipalities, especially the built-up Gateway Cities. Auto ownership is lower where household incomes are lower, a finding that aligns with a 2011 Brookings Institution study that found the majority of zero-vehicle households in the U.S. are located in cities and are lower-income households. This is equally applicable to the Boston-Cambridge-Quincy, MA-NH statistical area, with 58.1% of zero-vehicle households qualifying as low-income.¹⁷

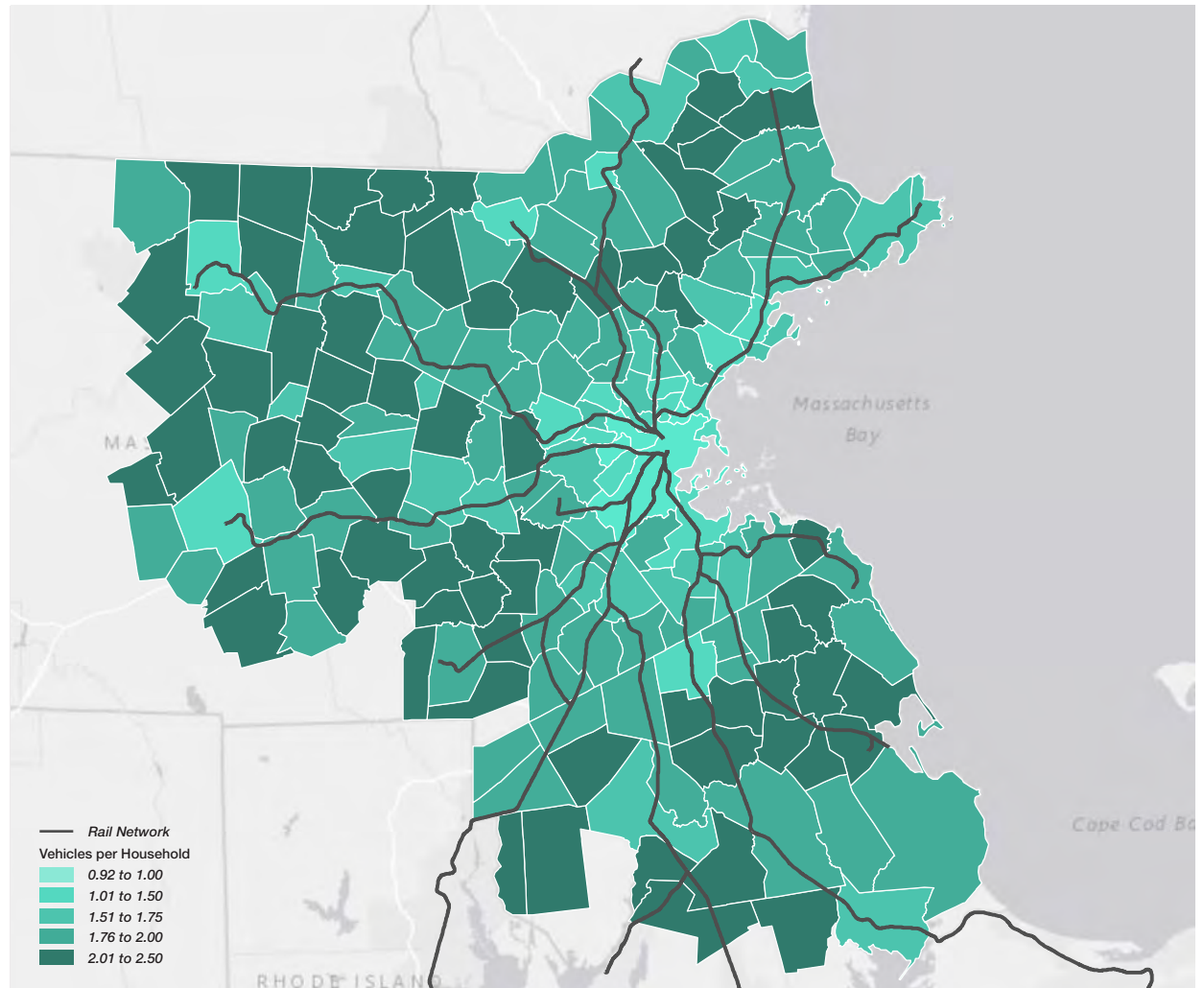


Figure 13: Vehicles per Household in the Study Area

2015

10 Miles



Assembly Row, an example of local transit-oriented development
 Photo Source: Todd Van Hoosear / Flickr

Data from the MassBuilds development database were analyzed to determine the growth of transit-oriented development along commuter rail lines.¹⁸ The data were obtained from MassBuilds in May 2017 and contain information on the number of residential units and commercial square footage in various stages of development within a half mile of 187 individual MBTA stations.

Since 2010, 9,627 new housing units and 6.5 million square feet of new commercial space either have been completed or are under construction within a half mile of a commuter rail station. Projects in the planning stages within a half mile of commuter rail stations accounted for an additional 11,923 housing units and 14.2 million square feet of commercial space.¹⁹ Longer-term projects designated as projected are planned to account for 9,909 housing units and 12 million square feet of commercial space.

Of the total number of projects (completed, under construction, and planned) around the MBTA commuter rail stations included in the dataset:

- those around South Station accounted for 18% of housing units and 27% of commercial square footage,
- those around North Station accounted for 10% of housing units and 9% of commercial square footage, and
- those around Back Bay accounted for 8% of housing units and 10% of commercial square footage.

3.3 Guiding Principles

For the purposes of this Feasibility Reassessment, a set of Guiding Principles was developed. These principles provide the framework for creating the service plans for the different service alternatives, and they are the standards by which these alternatives will be evaluated.

Primary Principles

These address the major problems the NSRL is intended to solve:

- Design a system to enable service patterns that support the MBTA Focus40 goals and objectives
- Increase the capacity of the MBTA's commuter rail network to bring commuters into Downtown Boston and Back Bay during peak commuting hours.
- Improve the transit accessibility to employment opportunities in Boston's urban core, particularly for residents on the north side of the Boston metropolitan area.
- Relieve congestion on the MBTA's rapid transit network (in particular on the Orange Line) by directly connecting commuters with their final destination.
- Improve the MBTA's ability to efficiently maintain its rail fleet.

Secondary Principles

These are additional problems the NSRL can help address, but are not the primary motivation for advancing the project concept:

- Reduce the physical footprint of rail layover facilities (both at the downtown terminals and elsewhere in the urban core), freeing these locations up for higher and better use.
- Reduce the emissions associated with the commuter rail system in the urban core through the electrification of portions of the network.

3.4 Best Practices and Emerging Trends

Since the 2003 DEIR (the most recent assessment of the NSRL), advances in tunneling technology and practice have helped make large tunneling projects easier and less expensive. The information gathered in the following pages provides an indication of how far the state of the practice has come since 2003 and offers valuable lessons for the NSRL project.



Tunnel for the 7 Line Extension in New York to the 34th Street / Hudson Yards Station

Photo Source: MTA / Flickr

Peer Project Summary

Fifteen peer projects were examined to understand the details of projects similar to the NSRL. These projects — a mix of urban subway and suburban-metro services and infrastructure from around the world — each included substantial subway and underground station construction and as such were deemed representative projects for the NSRL:

- Barcelona, Spain (Line 9/10)
- Leipzig, Germany (City Tunnel)
- London, United Kingdom (Crossrail, Thameslink)
- Los Angeles, United States (Regional Connector, Gold Eastside Extension, Purple Westside Extension)
- Malmö, Sweden (City Tunnel)
- Melbourne, Australia (Metro Tunnel)
- New York City, United States (East Side Access, 7 Line Extension, Second Avenue Subway)
- San Francisco, United States (Central Subway Phase 2)
- Sydney, Australia (Sydney Metro)
- Zurich, Switzerland (Durchmesserlinie)

Cost information was not available for most projects outside of North America, and not at all for concession (public-private partnership) projects, where cost details are confidential. As a result, the cost analysis herein is limited.

However, the review resulted in some insights into the method of construction for and the scope of similar projects. The size and length of the subway projects ranged from just 1.5 miles to 19 miles, but about one-third of the projects were less than 2.5 miles. Of the projects with underground stations, the majority were cut-and-cover rather than mined (except the 46 stations of the Barcelona Line 9/10).

Costs per mile vary widely across the projects. Some of the major outliers were as follows:

- The San Francisco Central Subway project, a 1.4-mile-long light rail subway with three stations, with total per track mile tunnel costs of \$112m per mile — about double the other examples
- The 7 Line Extension in New York to the 34th Street/Hudson Yards station, with a total cost of \$2.4bn for a 1.5-mile extension and one new station
- The Barcelona Line 9/10, 13 miles of bored tunnel plus stations and an additional 2.5 surface/elevated miles, for a total cost of US\$8.4bn — half the per track mile cost of either of the other outlier projects

Costs per track- and tunnel-mile on the other projects ranged from about \$36m (New York's Second Avenue Subway) to about \$65m each for LA's Regional Connector and Purple Line Extension 2. The cost per volume (per cubic foot) ranged from about \$23 for the Second Avenue Subway to about \$45 for the LA projects.

Station costs are another large expense, with total costs ranging from \$230m to more than \$1.3bn (Second Avenue Subway). The unit costs (costs per linear foot of station) ranged from \$285,000 for LA's Regional Connector to \$722,000 for the Second Avenue Subway. The LA Purple Line stations ranged from \$340,000 to about \$485,000 per linear foot.

The Second Avenue Subway had low tunneling costs and high station costs, and the LA Regional Connector had low station costs and midrange to high tunneling costs. No project reviewed had both low tunnel and station costs.

Peer Group Session

MassDOT, as part of the NSRL Feasibility Reassessment study and process, convened a peer group on October 19, 2017, to consider the work to date at the 10-week point of the study. Attendees were asked to provide guidance for the project and identify best practices from their cities.

Members of the peer group were as follows:

- Becca Nagorsky, Rapid Transit Project Planning, Planning and Policy Division, Metro-linx, Toronto
- Jeanet Owens, Program Management/Regional Rail, Los Angeles Metro
- Matt Preedy, Director of Construction Management, Sound Transit, Seattle
- Ron Hopkins, Assistant General Manager of Operations, Southeastern Pennsylvania Transportation Authority, Philadelphia
- Edward La Guardia, Michael Baker International, formerly Chief Engineer, Southeastern Pennsylvania Transportation Authority, Philadelphia

These agency staff were joined by three construction industry executives:

- Jack Brockway, President, Herrenknecht Tunneling Systems USA, Inc.
- Jim Marquardt, Senior Vice President, J.F. Shea Construction, Inc.

- Norbert Fuegenschuh, Executive President, BeMo Tunneling USA

Prior to an afternoon briefing session, MassDOT conducted an orientation walk from South Station to North Station, considering the various alignments and explaining potential constraints and conflicts. Agency attendees then presented on their respective projects, and the industry experts shared insights on best practices. The day wrapped up with a progress update from the NSRL project team and a presentation on purpose and need from the NSRL Working Group.

Key conclusions from the day included the following:

- Maintain a focus on developing strategic network goals against which to evaluate proposed system elements.
- Identify benefits to all system users, rather than focusing on just a few.
- Take the eventuality of risks seriously, including significant contingencies (50 to 60%), and spread the responsibility for the risk to match the significant unknowns of the project.
- Put in place project delivery methods that help anticipate project costs and risks.
- Understand the balance between operational efficiency and ease of use for passengers.
- Structure operations to minimize unintended effects (such as longer routes having less recovery



time and a subsequent increase in delays, or new stations adding journey time to those farther out on the system).

- Ensure the outlying infrastructure (beyond the limits of the major project) can support the full potential of the major investment.
- Engage early with contractors in order to get feedback on the project.
- Maintain momentum for the project, and build a coalition of influential supporters for the project.

Tunnel Boring Machines

The majority of the tunnels would be constructed using tunnel boring machines (TBMs), which have developed in both capability and technology over the last three decades, resulting in the ability to develop larger-diameter TBMs, as illustrated in Figure 14. Since the 1997 NSRL Technical Report No.3: Schematic Design Report was prepared, TBMs of over 41ft in diameter have been used in major tunneling projects, up to the current maximums of 57ft 6in in soft ground (both for the State Route 99 Alaskan Way Tunnel in Seattle and the Tuen Mun to Chep Lak Kok connection in Hong Kong) and 51ft 3in in rock (Italian Motorway Pass A1).

TBM technology has also improved the ability to excavate tunnels under high groundwater pressures, and the amount of settlement caused by TBM tunneling has steadily reduced over the last two decades, due to the increased sophistication of TBM control systems and rapid development of chemical conditioners to control the excavated material. This increased level of control is likely to reduce the extent of mitigation needed to building foundations to avoid settlement damage.

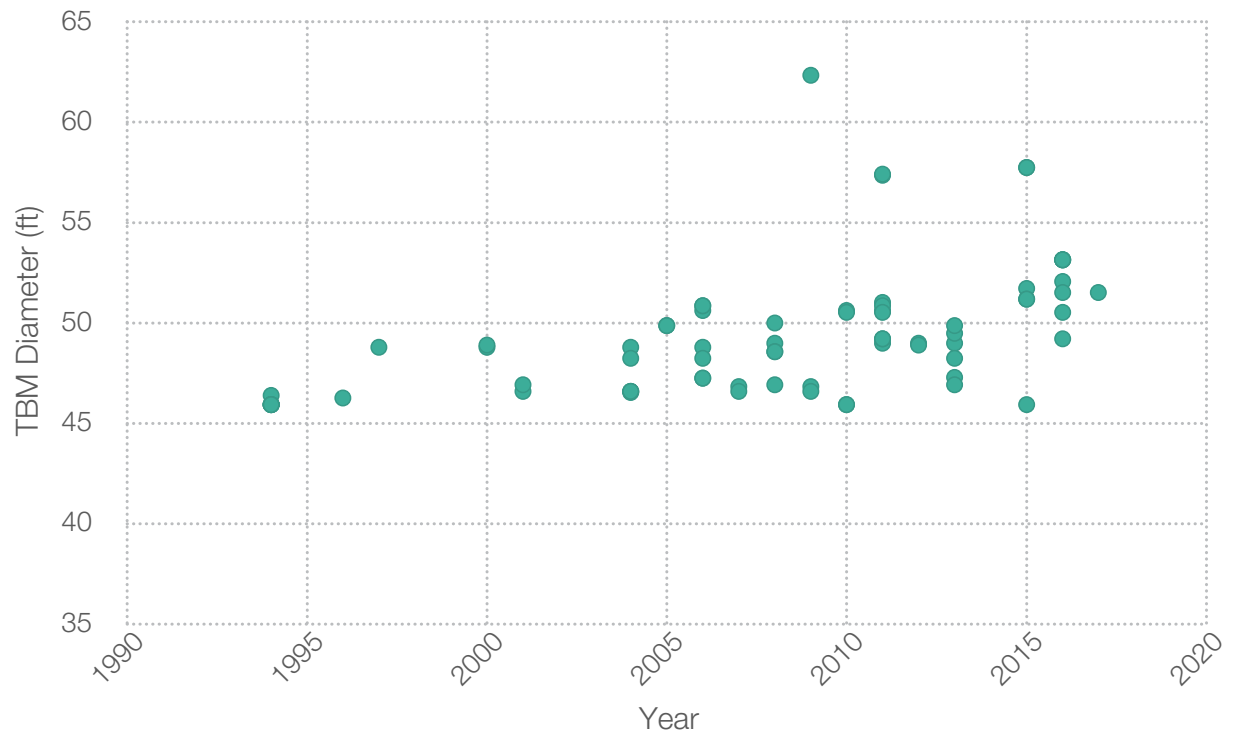


Figure 14: Increase in TBM Diameters

1990–2017

Source: <https://www.tunneltalk.com/Discussion-Forum-Mega-TBMs.php>

Motive Power

The 2003 study recommended the use of dual-mode locomotives, allowing electric operations within the tunnel and any other electrified areas, and diesel mode where electrification is not available. This would allow the existing MBTA coach fleet to be utilized through the tunnel.

Recent examples of dual-mode locomotives (specifically in North America, the ALP-45DP) have shown that they can offer performance in diesel and electric mode similar to that of single-mode diesel locomotives and electric locomotives, respectively. While capital costs can generally be expected to be greater for a dual-mode locomotive than for an equivalent diesel locomotive, dual-mode locomotives generally have maintenance costs comparable to single-mode diesel locomotives and significantly lower operating costs when operating in electric mode than when operating in diesel mode (see Table 7).

In terms of operations, some current dual-mode locomotives can change modes (between diesel operation and electric operation) while in motion, while others must be stopped to complete the change. Stationary mode changes, when required, typically take less than two minutes to complete and can be completed during station stops — the mode change itself can have little impact on overall run time.

One development that could ultimately make dual-mode locomotives unnecessary in the future is that of fully electric battery vehicles, supplemented with some sections of electrified territory. Batteries and ultracapacitors, which have begun to be tested by railroads in North America and worldwide, have potential to lower the emissions of rail systems. While still in the early stages, these technologies are expected to continue to improve considerably in the coming years, bringing down prices and improving their economic feasibility.

Item	Cost per Locomotive Mile (2017 dollars)	Cost per Locomotive Mile, Compared to Diesel Operations
Diesel Propulsion	\$8.12	-78%
Electric Propulsion	\$1.80	
Diesel Locomotive Maintenance	\$5.66	0%
Diesel/Electric Dual-Mode Maintenance	\$5.66	

Table 7: Locomotive Operating and Maintenance Costs by Type ²⁰

Given that limitation, battery tender railcars appear to be a promising technology in the mid-term. These cars could be placed in trainsets immediately behind a locomotive to power it through environmentally sensitive areas. In addition to having zero onboard emissions, the battery-tender-car concept would also have the specific advantage of being compatible with existing electric locomotives.

Battery component costs are forecast to decrease by two-thirds between 2012 and 2030, which is expected to minimize the differences in cost between conventional diesel locomotives and near-zero or zero-emission locomotives. However, battery tender technology remains in the conceptual stage, and additional research will be needed to assess its feasibility for the NSRL project.



Bombardier ALP-45DP locomotive

Source: Wikimedia / Fan Railer

4. Service Planning



4. Service Planning

A key aspect of the Feasibility Reassessment process is the creation of service alternatives that align with the vision of the NSRL, ensuring robust service levels to effectively utilize the capacity of the NSRL tunnels. This chapter describes the process of designing, evaluating and selecting service plan alternatives for the NSRL project. The routings and frequencies chosen directly influence ridership, operational costs, fleet size, and base infrastructure requirements for the overall project.

4.1 Background and Previous Studies

Previous service planning efforts for the NSRL project explored a number of alternatives, all aiming for a 2025 build year. In addition to No Build and tunnel alternatives, the 2003 study examined two Transportation Systems Management (TSM) alternatives that focused on enhancements to existing transit systems. The two TSM alternatives were a dedicated shuttle bus service between North and South Stations and increased service on the MBTA Orange Line. This Feasibility Reassessment focuses on evaluating a No Build alternative, a surface improvements only alternative, and several tunnel alternatives.

Operational assumptions for the 2003 study were based on 2020 commuter rail schedules provided by the MBTA. Tunnel headways were set at 4-minute minimums, and frequencies for each line were 30 minutes or less at the peak and 60 minutes or less during off-peak periods. The 2003 study assumed that North Station surface terminal tracks would remain, even with a tunnel alternative. This Feasibility Reassessment makes North Station an underground station only in all the tunnel alternatives.

In the 2003 study, line pairings were developed for both two-track alternatives (one using the Back Bay Portal and the other using the South Bay Portal) and for the four-track alternative. Both two-track alternatives connected the Lowell Line with Amtrak services on the Providence Line (as in this Feasibility Reassessment), with Amtrak trains running up the Fairmount corridor in the South Bay Portal alternative to achieve this pairing. The four-track alternative created through-running pairs for every commuter rail line, including the Old Colony Lines. This Feasibility Reassessment does not route the Old Colony Lines through the tunnel in any alternative.

The 2003 study assumed that one-third of Amtrak intercity service (or up to eight trains per day for the two-track alternative and 18 trains per day for the four-track alternative) would continue through the tunnel, but the majority would still terminate at South Station. The proportion of Amtrak service assumed to be running through the tunnels is the same for this Feasibility Reassessment. In 2003, the trains continuing beyond the tunnel would terminate in Woburn, with a cross-platform transfer to the Downeaster services at this station.

A main takeaway of the 2003 study was a projection that the commuter rail lines coming into North and South Stations would continue to see an imbalance in passengers even with through-running service, which “presents challenges in operating the rail tunnel during peak periods.”

4.2 Service Plans Considered

The NSRL project team considered nine service alternatives as part of this Feasibility Reassessment, each providing a different level of service and infrastructure requirements. There are two surface alternatives and six tunnel alternatives (three two-track and three four-track), in addition to a No Build alternative, detailed in Table 8.

Alternative	Service Levels	Capital Assumptions	South Coast Rail Alignment
No Build	2017 schedules	No expansion of South Station. North Station programmed/committed improvements (including drawbridge)	Via Middleborough
South Station Expansion & Regular Service (No NSRL)	South Station Expansion (SSX) schedules (base year 2013)	New platforms available in SSX Alternative 3, Fairmount improvements, North Station programmed/committed improvements	Via Stoughton
South Station Expansion & All-Day Peak Service (No NSRL)	Use full capacity of expanded South Station. Peak levels of service all day, where possible (within infrastructure constraints).	As above	Via Stoughton
NSRL Minimum Service (two-track)	Maintain SSX level of service. Hourly off-peak service, where possible.	No expansion to South Station and no increase in fleet size. No surface North Station	Via Stoughton
NSRL Minimum Service (four-track)	As above	As above	Via Stoughton
NSRL Regular Service (two-track)	Double peak service levels from minimum tunnel. Hourly off-peak service, where possible.	No expansion to South Station. Increase in fleet size. No surface North Station	Via Stoughton
NSRL Regular Service (four-track)	As above	As above	Via Stoughton
NSRL All-Day Peak Service (two-track)	As much service as can be supported by the infrastructure. Continue max tunnel peak levels of service all day, where possible (within infrastructure constraints).	As above	Via Stoughton
NSRL All-Day Peak Service (four-track)	As above	As above	Via Stoughton

Table 8: Service Alternatives for Feasibility Reassessment

Caveats

The NSRL project team followed the service-planning process agreed to by MassDOT and the NSRL Working Group in developing the Feasibility Reassessment scope of work. As such, the analysis is ‘supply-based’ (based solely on the minimum service levels set for the alternatives) rather than ‘demand-based’ (based on evaluating the market to determine where service should be increased), although the four most promising service alternatives were subjected to a ridership assessment (along with the No Build alternative). The project team created detailed schedules to ensure that trains could feasibly run at the required service levels, but in some cases, headways on single-track sections are more frequent than those currently endorsed by MBTA. Additionally, some of the all-day peak service plans have such frequent headways that maintenance can be allowed only at night, as opposed to current MBTA practice, which services some vehicles and conducts track maintenance in between peak times.

Line Pairings

The line pairings within the new tunnel infrastructure will influence the benefits of the NSRL project, including ridership, mode shift, and reductions in VMT and travel time. To maximize the efficiency of a new link between the commuter lines currently running into North Station and those running into South Station, the Feasibility Reassessment has paired these lines according to several criteria, described in the next few paragraphs. The line pairings for the tunnel alternatives are illustrated in Table 9 and the figures on the following pages.

NSRL Regular & All-Day Peak Service (Two-Track)			NSRL All-Day Peak Service (Four-Track)		
Fairmount	to	South Station	Dedham*	to	South Station
Middleborough	to	South Station	Middleborough	to	South Station
Kingston/Plymouth	to	South Station	Kingston/Plymouth	to	South Station
Greenbush	to	South Station	Greenbush	to	South Station
Back Bay Portal					
Worcester	to	Newburyport/ Rockport	Worcester	to	Newburyport/ Rockport
Needham	to	Fitchburg	Worcester	to	Fitchburg
Franklin	to	Fitchburg	Needham	to	Haverhill
Dedham*	to	Fitchburg	Franklin	to	Haverhill
Providence/Stoughton	to	Lowell	Providence/Stoughton	to	Lowell
Providence/Stoughton	to	Haverhill			
			South Bay Portal		
			Fairmount	to	Newburyport/ Rockport
			Fairmount	to	Fitchburg

Table 9: Line Pairings for the Tunnel Alternatives

*‘Dedham’ indicates trains that originate and terminate at the Dedham Corp. Center station on the Franklin Line

The line pairs in the two-track and four-track alternatives are similar, allowing for the maximum number of trains to be run on each individual line and maximizing the capacity of the tunnel(s). A challenge in pairing lines currently terminating at North and South Stations was balancing the smaller number of lines that currently run into North Station with the larger number of lines that currently run into South Station. This challenge was addressed by continuing to terminate the Old Colony Lines at the surface South Station, as they are today.

This Feasibility Reassessment of the NSRL differs from the 2003 study in that the current Feasibility Reassessment makes a technical and policy decision to assume reasonable constraints on the ability to deliver trains from branching lines into the NSRL. (This decision to avoid an unnecessary amount of additional infrastructure improvements to the wider commuter rail network was intended to limit the initial capital expenditure and reduce “scope creep”.) As a result, some service terminates at South Station in the two-track alternatives. In the four-track alternative, Fairmount service was prioritized to run through the tunnel to build on stakeholder aspirations for it to operate as more of a rapid transit-type service, leaving the Old Colony Lines to terminate at South Station, as they do presently.

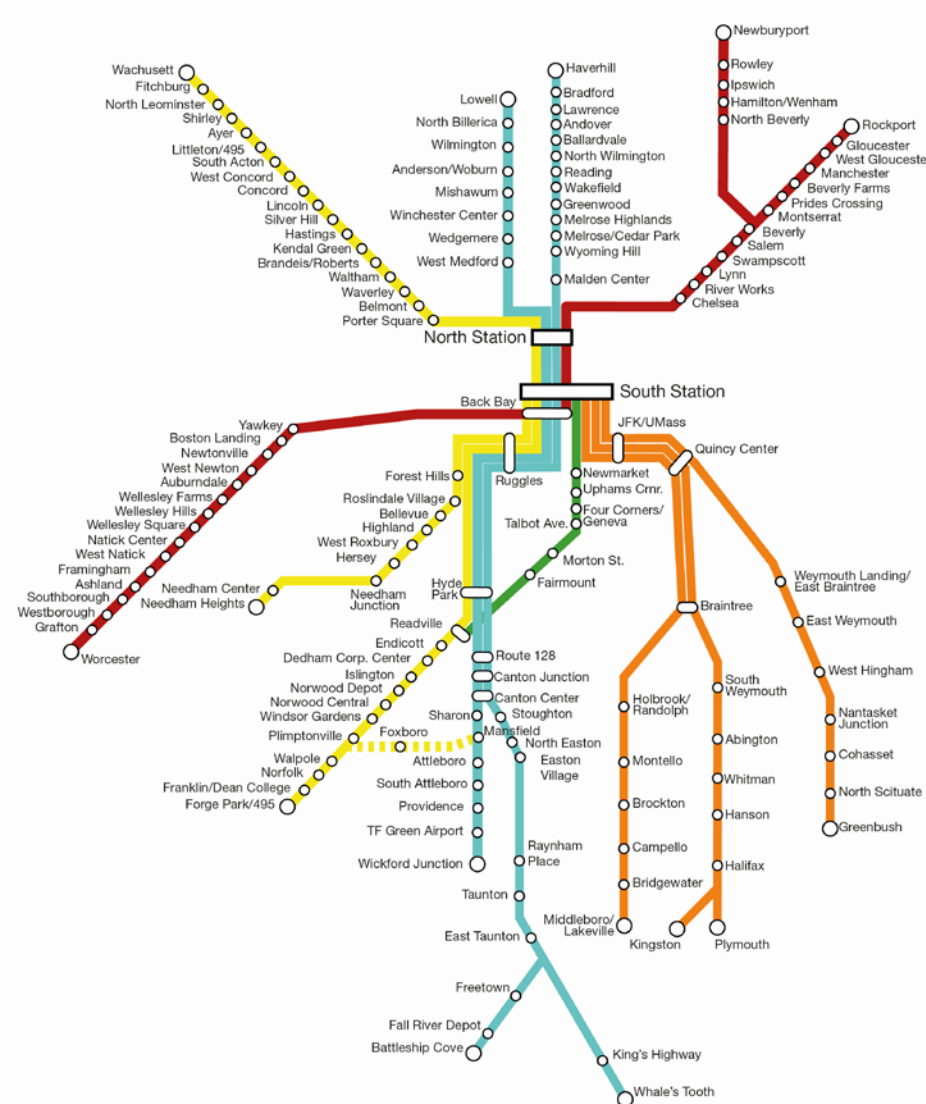


Figure 15: NSRL Regular and All-Day Peak Service (Two-Track) Tunnel Line Pairings

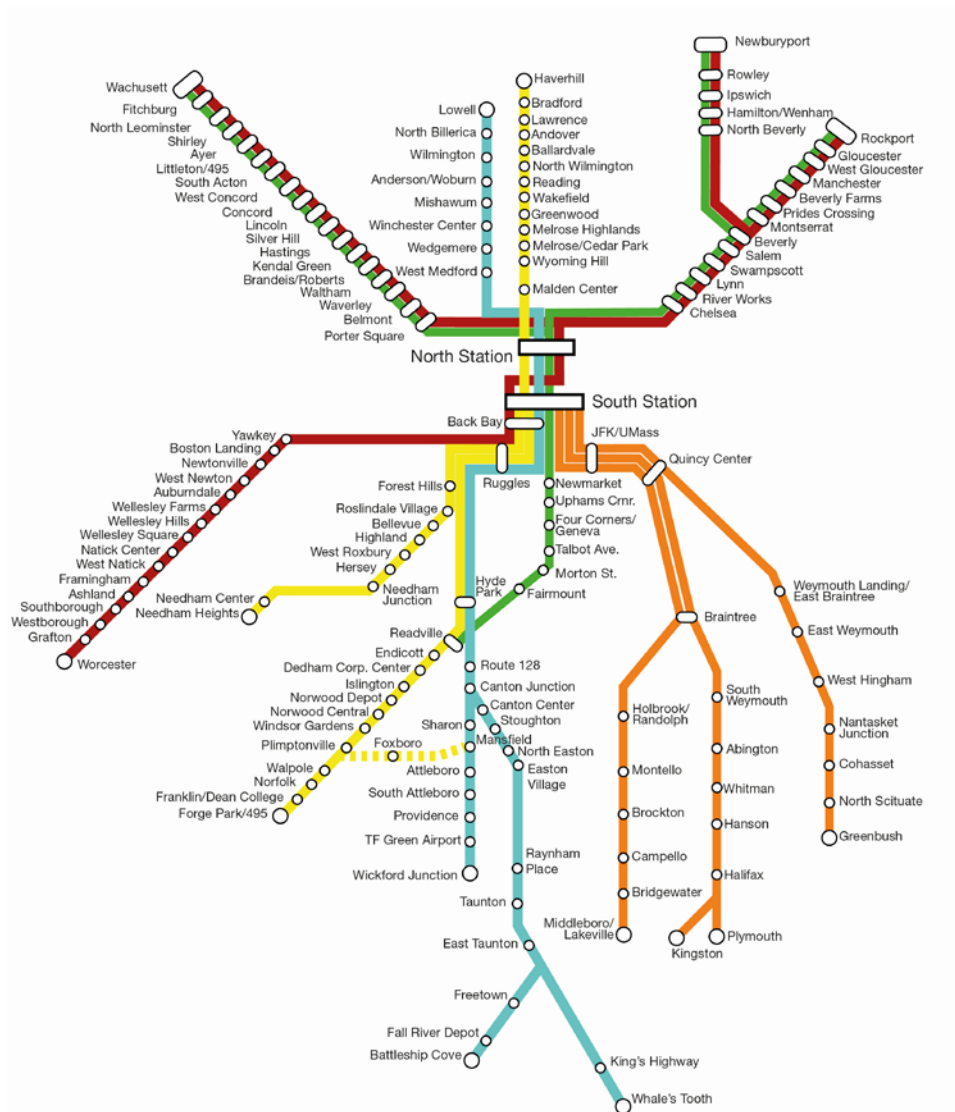


Figure 16: NSRL All-Day Peak Service (Four-Track) Tunnel Line Pairings

These line pairs have been determined by the following factors:

- Amtrak connections – linking services that currently terminate both north and south of the city to boost efficiency and create new connections
- All travel-to-work trips (both by transit and other modes – primarily auto) between north and south destinations – building on areas where there is already demand between destinations
- Connections to employment centers – linking more people to areas with a large number of jobs
- Capacity – pairing lines with similar frequencies, understanding the constraints of the entire network

In all of the alternatives, the Lowell Line is paired with the Providence/Stoughton Line to extend Amtrak's NEC to the northern suburbs and eventually allow electric service to as far north as Lowell. This pairing also assumes shared use of the Amtrak electrical overhead-contact system infrastructure from Providence to Boston and extending into the northern suburbs (allowing connections to Route 128 and potentially I-495). Using the NEC Future document (Federal Railroad Administration, 2017) as a guide, Amtrak express trains would continue to terminate at Boston South Station, but regional electric trains could use the tunnel and terminate at either Anderson or Lowell. Amtrak service from Springfield to Boston and from Boston to Maine could be combined into one dual-mode service, also operating through the NSRL. The intercity train routings are consistent with the line pairings and assumptions of the 2003 NSRL Study.

Prior to formal alternative modeling, CTPS provided regional Journey-to-Work data. The CTPS dataset organized census travel data (classified by “auto”, “transit”, and “total” trips) into districts roughly surrounding the commuter rail lines. The most common origins and destinations between the different districts were identified by charting a large matrix of the trips to and from these districts. This helped to determine where there was the greatest demand for trips and whether the demand for these trips could be satisfied by pairing commuter rail lines.

Results from this analysis suggest the districts containing Back Bay and South Station attract many trips, a demand satisfied by all pairings in the two-track alternatives and most in the four-track alternative. Only the Fairmount Line pairings do not travel through Back Bay because they need to use a different portal, which cannot physically be connected to Back Bay. Additionally, the districts along the Worcester Line attract many trips from the other districts, particularly those along the Fitchburg Line. Districts along the Fairmount Line have the most current trips to destinations along the Fitchburg Line, causing them to be paired in the four-track alternative.

While new ridership is anticipated, existing high-ridership lines connect to lines containing one or more large employment centers. This drove the connection of the high-ridership Newburyport/Rockport Lines with the Worcester Line, which

has the high-employment centers of Worcester and Framingham. Special consideration was paid to the large employment areas around Longwood Medical and Academic Area — encompassing about 45,000 employees and particularly accessible by lines paired with the Needham, Franklin, and Providence/Stoughton Lines — and advantaged by any line passing through Back Bay. As the Lowell Line is always paired with the Providence/Stoughton Line to connect Amtrak service, the next-highest ridership line, Fitchburg, is paired with Needham and Franklin in the two-track alternatives. Districts along the Haverhill Line also show a number of current trips to the Longwood area (determined from the origin–destination analysis), and are therefore paired with the Needham and Franklin Lines in the four-track alternative.

After the first three line pairing factors (as identified above) were considered, the line pairings were adjusted to maximize the efficiency of the tunnel(s), matching similar line capacities with one another. This step ensures each line is operating at or close to its maximum number of trains per hour. For example, the Fitchburg and Worcester Lines are paired in the four-track alternative because they have similar capacities and enable closer-in suburb-to-suburb trips. In some cases, this meant that line pairings with strong demand could not be considered because there was not available capacity on either the north or south portion of the line for them to be paired.

Screening Process

The original nine service alternatives described earlier in this section were screened down to five preferred alternatives using evaluation criteria and service plan metrics classified under the areas of Efficiency/Effectiveness, Equity, and Environment, as follows:

Efficiency/Effectiveness

- Peak-hour percentage of capacity (peak direction) – Measures peak-hour capacity utilization for North Station, South Station, and the tunnels in the two-track and four-track alternatives
- Peak-hour, peak-direction trips – All trips taken in the peak hour, and in the peak direction
- Number of hours the peak can be maintained
- Peak-hour vehicle requirements – Vehicle requirements for peak-hour trips, assuming a trainset (“consist”) of eight traincars
- Cost – Qualitative assessment of cost, classified as low, medium, and high
- Relief of the rapid transit network – Qualitative assessment of the potential to relieve crowding on the Red, Orange, and Green Lines

Equity

- Travel market – Calculation (using train capacities for an eight-car trainset) of how much passenger capacity has access to South Station and Back Bay in each scenario
- Pairings of journey-to-work pairs – Quantity of origin-destination trips facilitated by line pairings
- North-south connections to areas of high job density for commuter-rail-adjacent households – Score measuring the improvement in car-free rail access to jobs in the study area

Environment

- Additional miles electrified
- Construction impacts – Qualitative assessment of the impacts of construction, divided into low, medium, and high levels

These evaluation criteria were arranged in a matrix to facilitate decision-making between the nine service alternatives. MassDOT reviewed this matrix and chose five alternatives for further analysis, which are discussed in more detail in the following section.

4.3 Service Plans Extensively Studied

The five service alternatives for further analysis — No Build, South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (Two-Track), NSRL All-Day Peak Service (Two-Track), and NSRL All-Day Peak Service (Four-Track)— underwent more detailed assessment, most notably through the development of detailed schedules outlining train movements and identifying locations for upstream improvements to enhance capacity and address pinch-points (see Section 5.9 and Appendix B for more detail).

Table 10 provides an overview of the trains per hour for each commuter rail line under each service alternative. These frequencies have been influenced by the original service alternative requirements discussed in Section 4.2 and the capacity available on each line.

Systemwide Constraints

Both operating and physical infrastructure constraints on the MBTA Commuter Rail system limit the level of service that can be provided for each of the service alternatives. For example, the MBTA's maximum limits on headways, turnaround times, and junction margins can limit how closely trains can be run together. Physical constraints, like stretches of lines where only single tracks are provided, also limit total capacity. Additionally, it is difficult to provide regular, frequent headways while running variations on service, such as express and local trains.

Risks in Implementing Service Plans

The following represent some of the biggest concerns MBTA Operations has with the study's assumptions:

- Service disruptions on one or two tracks in the tunnel will cause ripple effects throughout the entire commuter rail system
- Assumptions about train loading/unloading time are much more aggressive than current experience
- Depth of stations is a concern during evacuation (and possible negative impact on customer experience due to longer time to exit stations)
- Rapid transit stations were not designed to accommodate transfers from commuter rail in the way they would happen now and may lack platform capacity to adequately do so
- Locations for additional layover and maintenance capacity have not been identified and are challenging to site

Service Alternative	Trains per hour									
	Newburyport / Rockport	Haverhill	Lowell	Fitchburg	Worcester	Needham	Franklin	Providence/ Stoughton	Fairmount	Old Colony (each line)
No Build	3-4 (P)	2 (P)	2-3(P)	2 (P)	3-4 (P)	2 (P)	2 (P)	3-4 (P)	1-2 (P)	1-2 (P)
	1-2 (OP)	1 (OP)	1 (OP)	1 (OP)	1 (OP)	1 (OP)	1 (OP)	1-2 (OP)	1 (OP)	<1 (OP)
South Station Expansion & All-Day Peak Service (No NSRL)	4 (AD)	3 (AD)	3 (AD)	3 (AD)	6 (AD)	2 (AD)	2 (AD)	4 (AD)	4 (AD)	2 (P) 1 (OP)
NSRL Regular Service (Two-Track)	4 (P)	3 (P)	3 (P)	4 (P)	4 (P)	2 (P)	2 (P)	6 (P)	4 (P)	2 (P)
	1 (OP)	1 (OP)	1 (OP)	2 (OP)	1 (OP)	1 (OP)	1 (OP)	2 (OP)	2 (OP)	>1 (OP)
NSRL All-Day Peak Service (Two-Track)	4 (AD)	3 (AD)	4 (AD)	6 (AD)	4 (AD)	2 (AD)	4 (AD)	7 (AD)	4 (AD)	2 (P) 1 (OP)
NSRL All-Day Peak Service (Four-Track)	4 (AD)	4 (AD)	6 (AD)	6 (AD)	6 (AD)	2 (AD)	4 (AD)	6 (AD)	4 (AD)	2 (P) 1 (OP)

(P) – Peak

(OP) – Off-peak

(AD) – All-day

All designations exclude late-night frequencies

Table 10: Overview of Service Alternatives

4.4 Capacity Assumptions

Rolling stock and infrastructure capacities play a significant role in determining the level of service that can be provided and how proposed investments can be efficiently utilized.

Train Capacity

MBTA currently operates a mix of single- and double-deck coaches into North and South Stations, with a mix of train types and sizes (services into South Station have both more and larger trains than those going into North Station). Currently operated trainsets (or consists) vary from five to nine cars.

This Feasibility Reassessment incorporates the MBTA Commuter Rail Fleet Plan, which anticipates the replacement of the system's current single-deck cars with 180-passenger double-deck cars. The plan identifies replacing 203 single-deck cars with 190 double-deck cars.

Coach type	Capacity (seated passengers)*
Amtrak standard train (with expected 2040 capacity increase)	400
MBTA single-deck coach	114
MBTA double-deck coach	180

Table 11: Coach Capacity Assumptions

*The capacity above records the seated capacity for an entire Amtrak train (6 cars), while the MBTA measures are per coach (MBTA Commuter Rail train lengths vary)

Tunnel Capacity

This Feasibility Reassessment bases its calculations on a tunnel capacity of 22 trains per hour (tph) in each direction. This metric is based on the operating environment in comparable projects currently constructed or underway, including the existing Amtrak and NJ Transit Hudson Tunnel into Penn Station New York (24 trains per hour) and the future London Crossrail. However, upstream constraints limit the maximum throughput of the tunnels and their efficient use. This is especially true for the four-track alternatives, which are limited in the number of trains that can run in the second tunnel because the South Bay Portal can only accommodate the

Fairmount and Old Colony Lines, which run a maximum of four or six tph, respectively.

These challenges mean that, absent significant upstream investment beyond the scope of the NSRL Feasibility Reassessment, the most realistic assumption is to operate 16 to 17 trains through the tunnel in each direction per hour (for context, this is more frequent service than currently provided on the Red Line).

Based on an entire fleet of double deck cars seating 182 passengers each and eight to nine coaches per train, No Build system capacity will be about 44,000 total peak hour seats.

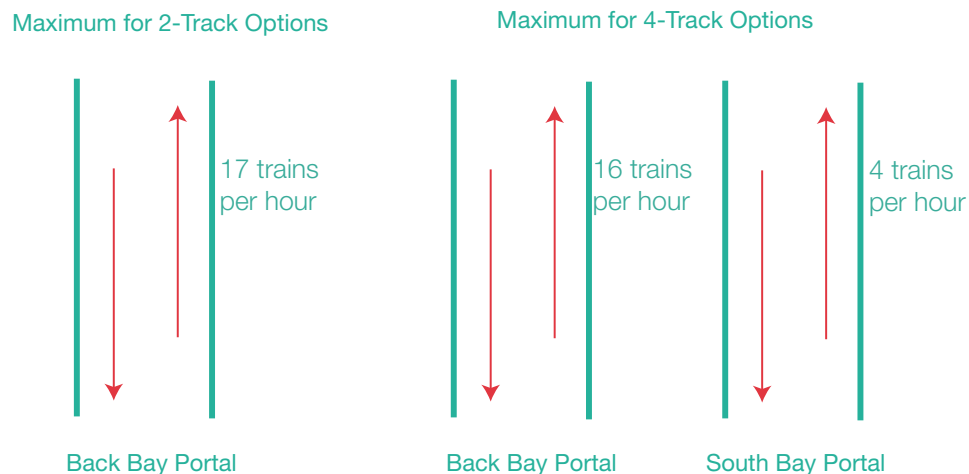


Figure 17: Tunnel Maximum Throughput (Trains Per Hour)

In the build options, capacity increases with both additional trains and additional coaches. In the South Station Expansion & All-Day Peak Service (No NSRL) alternative, the peak hour capacity approaches 48,000 seats (a 9% increase), while in the tunnel alternatives, capacity further increases into the double digits. In the NSRL Regular Service (Two-Track) alternative, the peak hour capacity totals about 56,000 seats (an increase of about 27%), and in the NSRL All-Day Peak Service (Two-Track) alternative, capacity increases to about 59,000 peak hour seats (a 34% increase). In the NSRL All-Day Peak Service (Four-Track) alternative, about 67,000 peak hour seats are provided, an increase of about 50%. Details are in Figure 18.

The tunnel has additional theoretical capacity beyond this; however, increasing the number of trains requires additional upstream improvements beyond those considered in this study and additional investment in rolling stock, including coaches and locomotives.

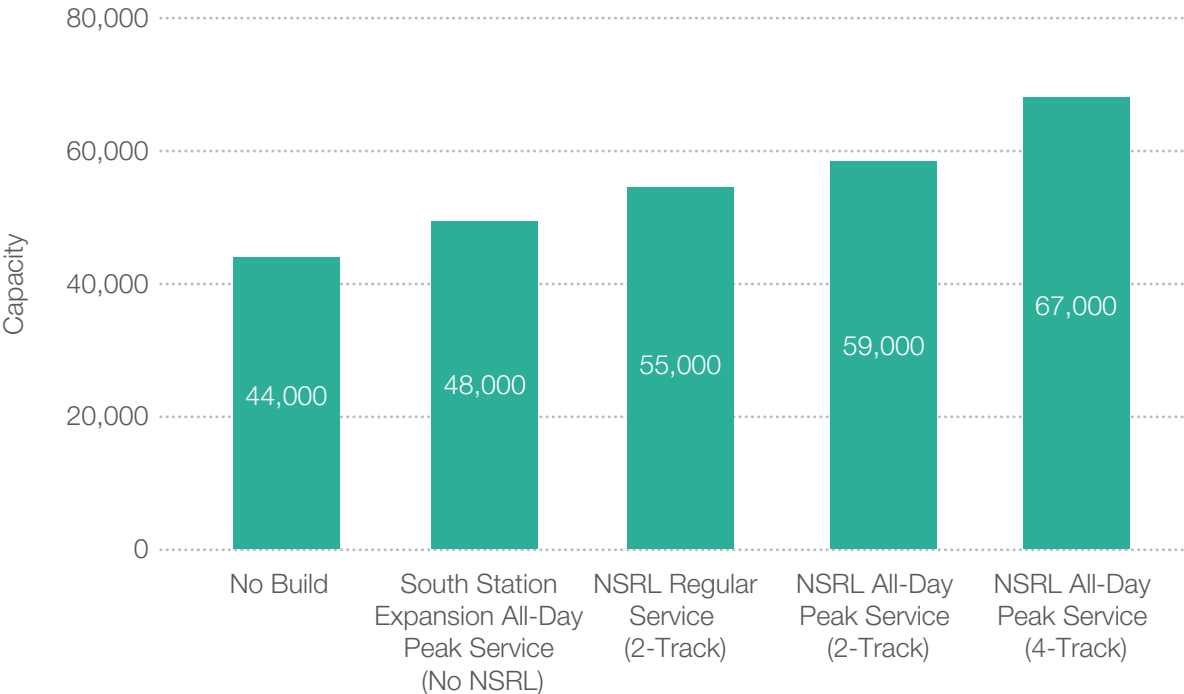


Figure 18: Peak-Hour Project Capacity

4.5 Ridership and Operating Costs

CTPS modeled the five service alternatives (including the No Build alternative) to forecast the differences in travel for each alternative. These forecasts facilitate the assessment of impacts and benefits for each alternative (the benefit-cost analysis is discussed in more detail in Chapter 7 of this report). Using the regional travel model described in Section 3.2 and assuming a 2040 build year, CTPS generated outputs based on all travel in the region and how it would be affected by the various build alternatives (in addition to the No Build alternative). For ease of analysis, the area served by commuter rail was divided into 39 regions.

The CTPS model estimates daily transit ridership and highway traffic volume based on changes to the transportation system — in this case, the build alternatives. The model set takes into consideration data on service frequency, routing, travel time, and cost for all services.

Key outputs for each alternative include quantified impacts to the transit and highway systems, as well as region-wide changes in the way people travel. Outputs specifically related to transit include ridership (the total number of commuter rail trips) and travel time (in-vehicle and total, which includes transfers). Outputs specifically related to the highway system include vehicle miles and hours traveled. Both the transit and highway outputs include data on trip purpose. The model outputs identify district-to-district and regional total flows, which show the details of travel broken down

by the mode chosen (transit or highway) and the distance traveled (transit segments or entire lines). These outputs can highlight the differences in travel between two districts for the alternatives when they are connected by commuter rail and when they are not.

For the purpose of the ridership estimates, it was assumed that parking at stations would be unconstrained (i.e., drive access trips would not be limited by current parking lot capacity) to allow for future transportation changes, including more use of ride share for pick-ups and drop-offs.

Projected Ridership

Table 12 shows the projected 2040 ridership for each of the alternatives and the percent change versus the No Build alternative.

Service Alternative	Projected Ridership* (2040)	Percent Increase from No Build
No Build	150,000	
South Station Expansion & All-Day Peak Service (No NSRL)	195,000	30%
NSRL Regular Service (Two-Track)	195,000	30%
NSRL All-Day Peak Service (Two-Track)	225,000	50%
NSRL All-Day Peak Service (Four-Track)	250,000	67%

**daily weekday trips*

Table 12: Projected Ridership (2040) per Service Alternative

CTPS's ridership forecasts for all five service options can be summarized as follows:

- 2040 No Build commuter rail ridership totals about 150,000 boardings per day, an 18% growth over the 2016 base year. This roughly 1.5% growth per year is consistent with past trends on MBTA Commuter Rail.
- The South Station Expansion & All-Day Peak Service (No NSRL) alternative shows an increase to about 195,000 daily boardings, a 30% increase over the 2040 No Build. This ridership increase is spread across the system, as this alternative increases frequency for many trips. Overall, the south side sees a greater increase (34%) than the north side (24%), with a significantly higher total number of trips on the south side.
- The NSRL Regular Service (Two-Track) alternative has a daily ridership of about 195,000, the same percentage increase over the 2040 No Build. Despite the presence of a tunnel to enable through-running trains, less midday service than the all-day peak alternatives causes the results of this alternative to be the same as those of the South Station Expansion & All-Day Peak Service (No NSRL).
- The NSRL All-Day Peak Service (Two-Track) ridership increases to about 225,000 daily boardings, a 50% increase over the 2040 No Build. Com-

pared to the South Station Expansion & All-Day Peak Service (No NSRL) alternative, almost all the increase is from boardings on the north side of the system – with north side boardings increasing by 75%. This is likely attributed to the ability for north side commuters to connect directly to areas south of North Station, as large increases are seen at South Station, Back Bay, Ruggles and others, while North Station sees declines in boardings.

- The NSRL All-Day Peak Service (Four-Track) ridership increases to about 250,000 daily boardings, a 67% increase over the 2040 No Build and an 11% increase compared to the NSRL All-Day Peak Service (Two-Track) service.

Across each 2040 alternative – whether surface or tunnel – certain lines perform better than others. Worcester and Providence services do not grow as strongly as others, and Franklin shows a decrease. This is perhaps due to the model putting greater emphasis on travel time relative to increases in frequency; however, it is likely that in actual practice ridership will increase on these lines. On this basis, the model results can be considered slightly conservative.

Forecasting Commuter Rail Ridership in Metro Boston

Who produces the forecasts: The Central Transportation Planning Staff (CTPS) maintains and uses a computerized travel model set to predict how many trips will occur. CTPS acts as staff to the Boston Region Metropolitan Planning Organization (MPO). CTPS was created in 1974 to provide continuing expertise in comprehensive, multimodal transportation planning and analysis. About 50 professionals work at CTPS.

What is the travel demand model and what does it do: Travel models predict how many trips will be made by people in a given region on a typical day, where those trips will go, and what modes and routes those trips will use. Travel models provide information about projects, programs, and policies for decision makers. Travel models are used in project development to predict how many vehicles will use a new or modified roadway, or how many people will board a new or modified transit line or link, such as the North South Rail Link.

How does the travel model work: Travel models are based on people's observed behavior, usually obtained from household travel surveys. Statistical analysis of the survey data yields the models that describe this behavior. The models then forecast future travel as population and employment patterns, costs of the different travel modes, and the transportation system changes are considered.

The CTPS travel model encompasses all of Massachusetts, all of Rhode Island, and a portion of southern New Hampshire; it represents weekday travel only, and is an "aggregate model set" that represents and forecasts travel for groups of travelers, rather than for individual travelers. The model is a planning-level tool, offering a 10,000-foot view and using trips between analysis zones (of which there are more than 5,700).

The model uses regional demographic inputs (as described in Section 3.2). The travel demand forecasts used in this Feasibility Reassessment are based on regionally adopted demographic forecasts. The MAPC develops socioeconomic forecasts for use by the Boston Region MPO, which are, in turn, used in the MPO's Long-Range Transportation Plan (LRTP). The current LRTP, *Charting Progress to 2040*, was adopted in July 2015. This demographic information is summarized in the MPO's Needs Assessment document (July 2015).²¹

Table C1 in Appendix C details the employment and population changes forecast for the Boston region, which are the basis for the travel demand forecasts. It should be noted that these forecasts were developed several years ago; however, they represent the current regionally adopted forecasts and are therefore used for all transportation analysis in the region. In these forecasts, employment grows by about 160,000 jobs between 2015 and 2040 (about 6%, or about 0.25% annually), and population is forecast to increase by about 510,000 (about 9%, or about 0.35% annually). More employment growth is forecast in the area within Route 128 than the area outside (55%/45%), while the population increases in both areas are about equal. The southern suburbs have about 15-20% more jobs and residents than the northern suburbs.

The four major steps in the travel-modeling process are as follows:

- Trip Generation. This step predicts how many trips, for each of several trip purposes, a household will make on a typical day.
- Trip Distribution. This step links trips from one place to another. Trips produced by households in one analysis zone are attracted to other analysis zones in direct proportion to the relative sizes of those other zones. Trip distribution forecasts the volume of trips from one place to another.
- Mode Choice. This step assigns the trips from every analysis zone to analysis zone by mode of travel, based on the relative times and costs associated with each available mode. Mode choice forecasts the way the trips identified in trip distribution are actually made (bus, car, walk).
- Route Assignment. This step routes trips on the cheapest and fastest links (compared to other available routes) for both roadway and transit trips. Trip assignment estimates the traffic and passenger flows on a transportation network.

Within each step are many other tasks that inform the process and play a role in how people choose to travel. A more detailed description of the model is available in Appendix C.

Train Miles/Hours

Train miles and hours allow for the estimation of operating costs, including maintenance. The calculations for train miles and hours are based on the following principles:

- Distances are derived from the current MBTA Commuter Rail track network
- Journey times are based on current schedule timings
- Non-revenue mileage and train hours are based on assumed trainyard locations. (A high-level assessment of yard capacity has been undertaken to identify indicative locations for overnight storage and staging, including some locations not currently in use.) The calculations do not allow for non-revenue moves between lines during operating hours or any additional movements required for rolling stock maintenance or refueling.
- Mileage and hours are based on the whole consist rather than per coach.

Table 13 shows weekday revenue and non-revenue train miles and hours for each of the five service alternatives.

Unsurprisingly, the NSRL All-Day Peak Service (Four-Track) tunnel alternative has the greatest number of revenue and non-revenue miles and hours, closely followed by the NSRL All-Day Peak Service (Two-Track) tunnel alternative. The NSRL Regular Service (Two-Track) tunnel alternative has the smallest increase in revenue miles/hours from the No Build alternative but has the third-highest increase in non-revenue miles/hours, reflecting the need to reposition trains in the off-peak periods.

Service Alternative	Weekday Daily Totals			
	Revenue Miles	Revenue Hours	Non-revenue Miles	Non-revenue Hours
No Build	16,420	530	800	30
South Station Expansion & All-Day Peak Service (No NSRL)	41,550	1,370	1,630	60
NSRL Regular Service (Two-Track)	28,290	950	2,300	80
NSRL All-Day Peak Service (Two-Track)	51,470	1,690	2,480	80
NSRL All-Day Peak Service (Four-Track)	55,230	1,780	2,800	90

Table 13: Weekday Train Revenue and Non-revenue Miles and Hours per Service Alternative

In order to allow for a consistent comparison across all service options, the No Build figures in Tables 13 and 14 are from Arup's estimates, which are within about 6% of operating numbers received from Keolis, the MBTA Commuter Rail operator.

Trains Required for Service

The identification of weekday revenue and non-revenue miles and hours allows for the calculations of train requirements for each service alternative, as detailed in Table 14. As described in Section 4.4, the assumption is that all new train cars required for service will be double-decker cars.

MBTA's schedules (as of 2017) require 67 consists (individual trains) using 364 coaches. The MBTA Fleet Plan calls for replacing the current single-level traincars with double-decker cars. This reduces the number of scheduled traincars to 316 and increases capacity adequately to serve the forecasted increase in No Build ridership.

Table 14 shows the rolling stock requirements for each of the five service alternatives. All of the build alternatives require an increase in overall fleet size, and Table 14 only illustrates coaches and locomotives in scheduled service. MBTA uses a spare ratio of about 11% for coaches and about 35% for locomotives, which increases the overall fleet requirements. In future planning stages, train storage and marshalling yards and tracks will need to be included in the analysis, as they have not been incorporated in this Feasibility Reassessment.

All of the build alternatives require significant increases in fleet size. These increases require both additional capital expenditure (for the cost of the additional yards, coaches, and locomotives,

assuming the existing base fleet is regularly renewed) and additional operating costs.

Finally, as service increases, and the currently scheduled weekday consists increase to more than 100, additional train crews and maintenance personnel will be required. This Feasibility Reassessment did not look at this in depth, so this should also be included in future planning stages.

For the purposes of the NSRL Feasibility Reassessment, one capital cost is utilized for the two-track alternatives pursuant to the study's scope. The capital cost differences between the NSRL Regular Service (Two-Track) and the NSRL All-Day Peak Service (Two-Track) is not significant, as the infrastructure requirements are identical and the fleet requirement – which is driven by the peak hour of train service – is almost the same. The combined fleet size is informed by the peak period requirement and a reasonable assumption of “short turns” and other operational practices that can reduce overall fleet requirements.

Unit Operating Costs

MBTA Commuter Rail operating costs for 2016 were \$17 per car mile and \$515 per car hour for the all-diesel fleet. In contrast, Philadelphia's SEPTA operating costs for 2016 were \$13.85 per mile and \$292 per hour for the all-electric fleet. Since there will be some combination of electric and diesel service, a range of costs is used as part of the financial impacts provided in the Feasibility Reassessment.

Service Alternative	Consists	Coaches (Bi-Level Equivalents/ Scheduled)
No Build	67	316
South Station Expansion & All-Day Peak Service (No NSRL)	116	524
NSRL Regular Service (Two-Track)	104	514
NSRL All-Day Peak Service (Two-Track)	121	527
NSRL All-Day Peak Service (Four-Track)	143	550

Table 14: Weekday Train Requirements per Service Alternative



Photo Source: Anthony Delanoix / Unsplash

5. Potential Alignments and Schematic Design

5. Potential Alignments and Schematic Design

5.1 2003 Alignments and Alternatives

All potential alignments to connect the northern and southern MBTA Commuter Rail lines that were evaluated in the 2003 DEIR followed the Central Artery/Tunnel project corridor between South Station and North Station. While a Congress Street alternative was initially considered, the alignment did not advance past the 2003 screening process because of anticipated construction and operational constraints in the limited rights-of-way underneath narrower downtown streets. In addition to a No Build alternative, the DEIR ultimately evaluated four tunnel alternatives along the Central Artery, with four different variables: the number of tracks in the tunnel, the location of southern portals, alignment of the underground South Station, and the inclusion of a Central Station, illustrated in Figure 19.

The build alternatives consisted of the following four configurations:

- Two-Track / Two-Station (Back Bay OR South Bay portals)
- Two-Track / Three-Station (Back Bay OR South Bay portals)
- Four-Track / Two-Station (Back Bay AND South Bay portals)
- Four-Track / Three-Station (Back Bay AND South Bay portals)

Each of the four alternatives was envisioned as one or more 41-foot-diameter deep tubes, with mined approaches and underground junctions but otherwise constructed primarily with tunnel boring machines along the length of the alignment underneath Central Boston.

All 2003 alternatives included tracks descending from a new Back Bay portal at a 3% grade (towards the new underground South Station). This new portal would serve all MBTA trains using the Northeast Corridor tracks from points south, as well as MBTA trains from Framingham/Worcester to the west, and those from Fall River and New Bedford from the south, following completion of the South Coast Rail Project. In addition, some Amtrak trains were anticipated to use the tunnel to connect to services north of Boston. The 2003 four-track alternatives also included South Bay portals connecting to the Fairmount and Old Colony Lines.

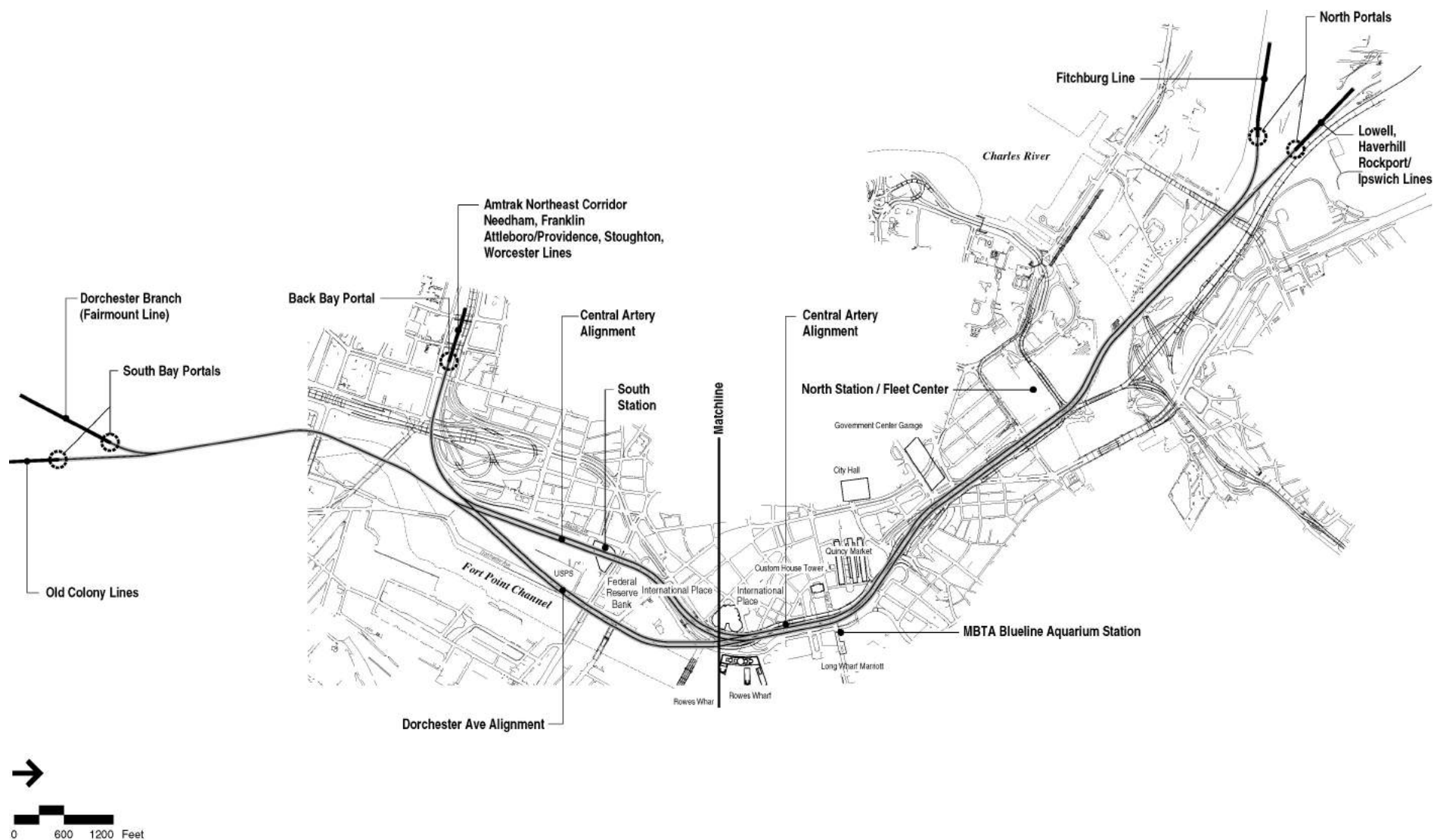


Figure 19: 2003 DEIR Alignment map

Source: NorthSouthRailLink Project •VHB/FRH, A JOINT VENTURE

Two underground South Station locations, illustrated in Figures 20 and 21, were proposed in 2003, but to avoid impacts to existing buildings, sites were considered only within the area bounded by Atlantic Avenue to the west and the Fort Point Channel to the east. The first alternative placed the new underground station directly underneath the surface tracks, east of Atlantic Avenue and connecting to the existing South Station headhouse. North of South Station, the rail tunnels intersect the footprint of the Federal Reserve Tower (the DEIR called for “close coordination with the Federal Reserve Bank” to mitigate construction impacts and “ensure the integrity of the building”). The second alternative placed the new underground South Station underneath Dorchester Avenue and the Fort Point Channel, avoiding the Federal Reserve property while continuing north under the Central Artery. The new underground North Station proposed in the DEIR was located underneath the Central Artery, with a precise site to be determined by more advanced engineering studies.

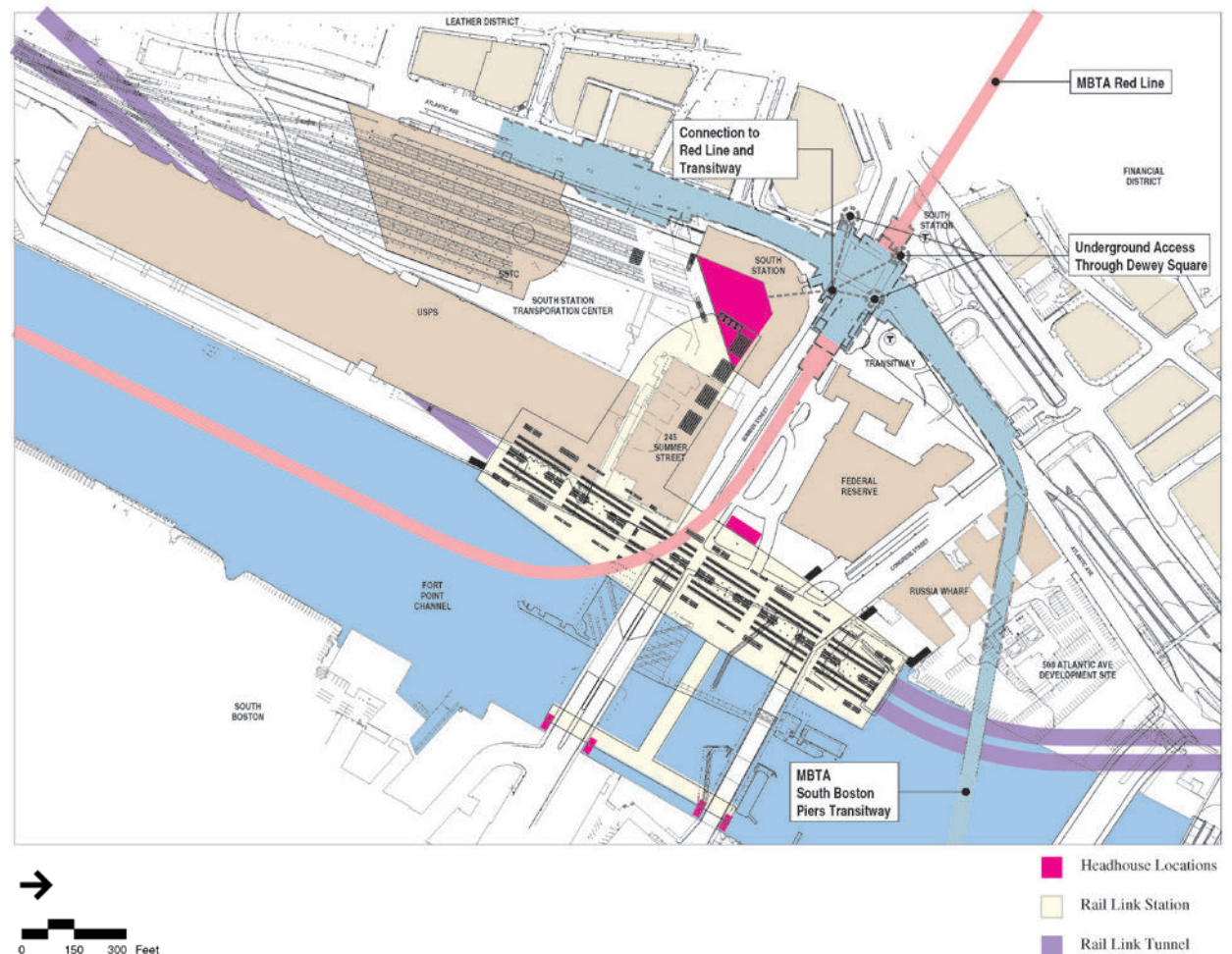


Figure 20: 2003 DEIR South Station location (Dorchester Avenue Alignment)

Source: NorthSouthRailLink Project •VHB/FRH, A JOINT VENTURE

In weighing the build alternatives, the 2003 DEIR considered several short-term construction impacts, including the need for access shafts, staging areas, and a minimally disruptive system for bringing excavated and construction material to and from the surface and off-site. The DEIR also identified potential conflicts between existing infrastructure and the alignment itself, particularly at the Back Bay approaches. While still in the portal area and at a shallow level underground, the proposed tunnels would pass through the I-93 and I-90 South Bay interchanges. The alignments could encounter multiple viaduct or approach ramp foundations for I-93, as well as tunnel jacking pit walls and drilled shafts for I-90. The proposed 2003 approaches did not directly conflict with any ramps or interchange structures, but underpinning would be necessary to pick up loads previously supported by interrupted caisson foundations.

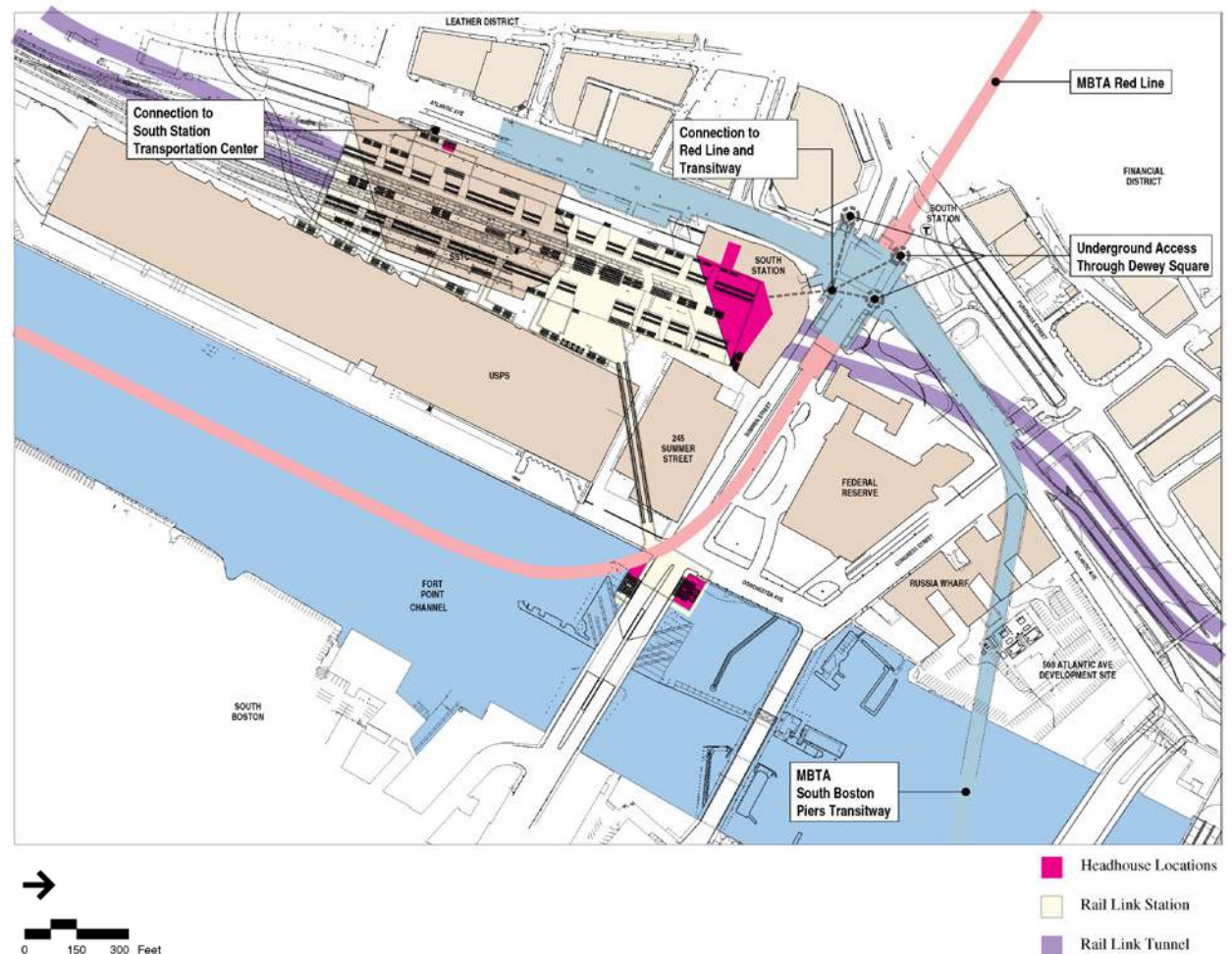


Figure 21: 2003 DEIR South Station location (Central Artery Alignment)

Source: NorthSouthRailLink Project •VHB/FRH, A JOINT VENTURE

5.2 Current Design Assumptions/Criteria

The design criteria developed for the 2003 DEIR and reviewed by an MBTA technical committee form the basis for the criteria for this Feasibility Reassessment. Table 15 contains the engineering design criteria distilled from four design standards:

- MBTA Commuter Rail
- Amtrak
- 1996 NSRL schematic design (used in 2003 DEIR)
- South Station Expansion

These engineering design criteria have been reviewed and approved by MassDOT and MBTA for the purposes of this NSRL Feasibility Reassessment.

Parameter	Ideal	Selected
Horizontal Alignment		
Minimum horizontal radius	1150ft	720ft
Minimum horizontal radius in stations	5750ft	
Spiral transitions	Required	
Maximum superelevation	3in	6in
Maximum unbalanced superelevation	1.5in	2.75in
Vertical Alignment		
Maximum gradient	2%	3%
Maximum gradient for special trackwork	2%	3%
Maximum gradient in stations	0.5%	1%
Compensation of grade for curvature	1 degree of curvature for every 0.04% vertical grade	No compensation
Rate of change of vertical curves	0.5% per 100ft	1% per 100ft
Clearances and Dimensions		
Horizontal clearance from centerline of tracks	8.5ft	
Track spacing	14ft	13ft (plus curve compensation)
Height from top of rail to catenary	19.5ft	
Allowance from dynamic envelope to top of tunnel (for catenary)	2.5ft	
Stations		
Platform length (Amtrak)	1050ft	
Platform length (MBTA)	850ft	
Platform width – side platform	22ft	12ft
Platform width – island platform	12ft	10ft

Table 15: Engineering Design Criteria

5.3 Station Design Principles

For this Feasibility Reassessment, station designs are developed using a modular component approach; components can be easily added or removed to suit individual station dimensions and integration with the urban environment at the surface. This flexibility allows the stations to accommodate platform lengths of either 850, 1,050, or 1,320ft, as well as the track configurations necessary to conform to design criteria.

All stations share the five characteristics listed below. Standardized components are illustrated and labeled in Figure 22.

- Modular connections at either station end facilitate convenient platform access and ease pedestrian flow.
- Additional access points along the platform (at approximately 80ft from station ends to avoid dead ends) enable safe emergency evacuation.
- Headhouses to enable access to the underground stations are designed to minimize the area needed at surface and urban intrusion. The locations for these structures are conceptual and seek to maximize important urban connections, by locating near planned developments that may accommodate a new entrance.
- Station headhouses contain elevators and escalators for circulation as well as ventilation and other ancillary station functions. This allows the

platforms to remain virtually free of bulky back-of-house areas. Ventilation shafts without entrance functions are also located in unobtrusive spaces, such as parking garages near the station.

- Walkways between headhouses and concourses utilize flexible elbow joints (see Figure 22) to allow a certain amount of leeway where station entrance locations can be placed at the surface and to accommodate future connections (if needed). For all stations, additional exits for emergency evacuation routes can be provided as necessary as local insertions into the urban environment.

Standardized station components:

- Concourse “elbow” allows entrance location to suit urban context above providing flexibility for station entrance locations at surface
 - Prioritizes minimum land take and urban intrusion
- Concourses house majority of back of house requirements (i.e. Public restrooms, communications closets, etc.)
 - Prioritizes passenger flow, operation, and experience

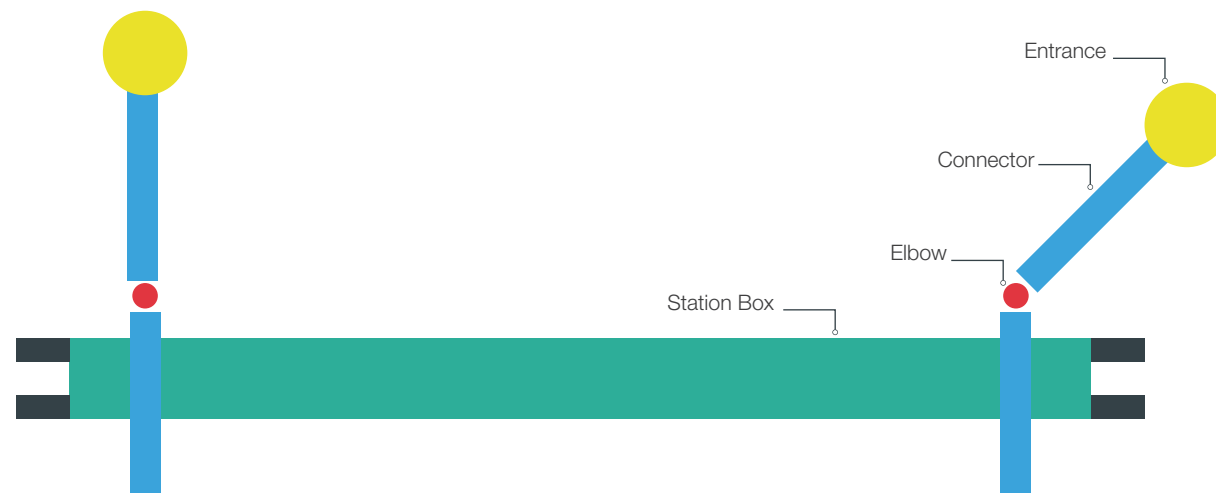


Figure 22: Station Design Principles

5.4 Tunnel and Underground Construction

The NSRL tunnel construction methods depend on the chosen alignment and depth of profile, as well as the alignment's urban and geological context. Cut-and-cover and tunnel boring machine (TBM) construction methodologies are considered, with TBMs varying in diameter to suit the needs of corresponding alignments. Portal areas are constructed using boat sections (a U-shaped trench with a continuous base slab and supporting retaining walls) with nearby underground sections built as cut-and-cover. Once sufficiently deep, or approximately one TBM diameter from the surface, bored tunnels are constructed using one or more TBMs launched from the proposed northern portal, with the TBM excavating the tunnel in the direction of the proposed southern portal.

Advances in tunnel technology and tunneling experience suggest that a large-bore alignment

through the center of Downtown Boston is feasible. This represents an evolution from the methodology used in the 2003 DEIR, where the initial screening process, informed by contemporary tunneling capabilities, considered and rejected this alignment. While the proposed South Street right-of-way (see Section 5.8) is narrower than the Central Artery corridor, the evolution of TBMs since 2003 has reopened the viability of this two-track alternative. Specifically, today's TBMs are wider in diameter, more maneuverable, and less impactful to adjacent structures. Tunneling technology now allows for sharper curves than before and tube diameters of 51ft, all with minimal settlement of buildings on either side of the street. This has an impact on the alignments considered and those taken forward for further analysis. Figures 23 and 24 display examples of a TBM cross-section and a launch pit.

The zone of influence typically refers to the area where settlement has the potential to impact structures or utilities. Typically, as a project is designed, structures or utilities within the zone of influence are assessed to determine the potential for damage. Many will be found not likely to suffer any damage, but some structures or buildings are particularly vulnerable due to geometry or material type. In this case, mitigation measures such as more controlled excavation methods, ground improvement, or modifications to the structure/utility would be applied.

The majority of the bored tunnel length for the proposed alignments and the mined portions of the proposed stations are in the argillite bedrock, a compressed, layered sedimentary rock native to Boston. Settlement in bedrock will be extremely low



Figure 23: TBM Cross-Section



Figure 24: TBM Launch Pit

and is unlikely to be even measurable at the surface. Ground movements can occur around excavation for station entrances and ancillary buildings. These excavations will be similar to building basements, and there is a long track record of managing ground movements to avoid damage to adjacent structures.

At either end of the alignments, the tunnels will travel through layers of clay and soil, (known as the overburden materials). In these areas, ground movements due to the tunnel are possible, but will be controlled within acceptable limits by using pressurized face TBMs. This technology continues to improve, and recent projects such as the 57.5-foot-diameter SR-99 soft ground tunnel in Seattle was completed with maximum surface settlement of less than 0.5 inches, which is typically below the level that would cause damage.

The most challenging area will be the interface between soil and rock, which if unmitigated could cause more ground movement (as soft ground moves through the TBM more quickly than rock does). On the proposed alignment, these areas will be in the vicinity of the I90/I93 junction at the southern end of the tunnel, and on the north side of the Charles River. Both these areas have surface access that would allow for mitigating ground treatment, should this be required.

5.5 Fire/Life Safety and Ventilation

Safety is the most important criterion in the design of the NSRL. Passengers and train crews using the tunnel need fresh air, and the tunnels must be designed to provide for quick and safe evacuation in the event of a fire or other unsafe condition. These fire/life-safety and other requirements are outlined in applicable codes and standards, with means of egress and ventilation as the two primary considerations. The safety systems, features, and procedures to meet those requirements result in specific implications for the physical design of the tunnel, above and beyond the alignments and stations described in the previous sections.

Appendix D outlines additional fire/life safety requirements considered for this project.

Means of Egress

In order to provide safe evacuation from tunnels and stations, building code and industry standards require certain means of egress features. The design of an egress system for emergencies overlaps with the passenger ingress/egress system used in normal operations (headhouses connected to vertical circulation), but may also result in additional design elements. These requirements are governed by the Massachusetts Building Code and the National Fire Protection Association Standard for Fixed Guideway Transit and Passenger Rail Systems (NFPA 130).

Egress from underground infrastructure like the NSRL tunnel and stations can be accomplished by providing doorways, corridors, stairs, escalators, and elevators. There are a number of variables that are weighed when determining the safe capacity of underground infrastructure and in determining design decisions, with the most important being the passenger load within trains and on platforms. Regulations typically require design to accommodate a peak load, including multiple trains arriving at a station at once, and a mix of boarding and alighting passengers. Figure 25 shows an example of how tunnel egress might be achieved.

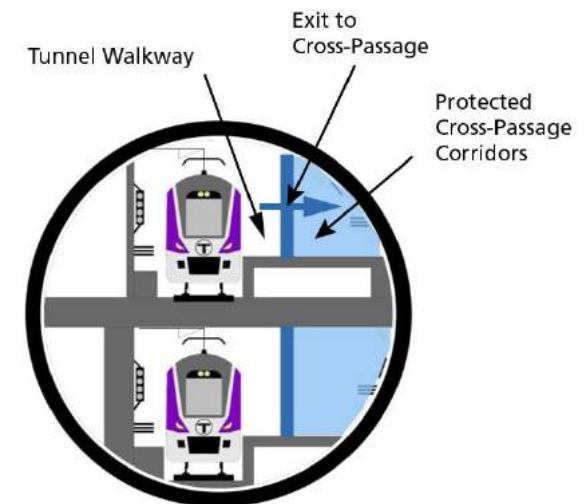


Figure 25: Example of Tunnel Egress

Within stations, a variety of design elements and performance-based tests must be met as per the standards, including the following:

- At least four exits must be provided for any space that serves greater than 1,000 people (as would be expected in NSRL stations).
- The maximum travel distance from any point on a platform to an exit from that platform is 325ft.
- Exits must be located within 82ft of each end of all platforms.
- The total evacuation time from the most remote area of a platform is four minutes to leave the platform, and six minutes to a Point of Safety (typically an above-ground area or an enclosed exit that leads to a public way or outside).

The details of permitted capacities, travel speeds, clear widths, and fire ratings for stations can be found in Appendix D.

Within tunnels, the required design elements vary based on the type of the tunnel system:

- For single tunnels, exits must be no more than 2,500ft apart (including exits at stations and tunnel portals).
- For dual tunnels, passageways between tunnels can be utilized in lieu of exits to ground level, and must be no more than 800ft apart (including exits at stations and tunnel portals).
- Single tunnels may be treated as dual tunnels if a fire-rated barrier is provided along the full length

of the tunnel between the two tracks.

- Walkways with minimum clear height of 80in must be located alongside tracks to provide a pathway from trains.
- Tunnel exits will have stairs to reach the surface, and an area of refuge (a hardened, fire-rated area) where people who cannot utilize stairs can await assistance.

The details of passageway size and capacity can be found in Appendix D.

All elements of an emergency egress path, whether in tunnels or stations, must be protected to control the spread of smoke and with emergency lighting.

The conceptual station and tunnel designs anticipate both day-to-day passenger flows and the emergency evacuation needs and requirements. A passenger faced with an evacuation scenario within a station would utilize the closest standard exit to reach the street level via passageways, stairs, and escalators. When faced with an evacuation scenario within a tunnel, passengers would exit the train onto a walkway and staff would direct passengers to the appropriate evacuation route. This route would lead to either a tunnel portal, station platform, emergency exit stairway (and area of refuge), or passageway between tunnels. Once in the opposing tunnel, passengers would continue along the walkway until reaching an emergency exit, station platform, or tunnel portal, each allowing exit to the surface. Given the travel distances and inherent safety

concerns with tunnels, trains will attempt to stop at stations, if possible, with tunnel evacuation as the last resort.

Ventilation

Ventilation must be provided within the NSRL tunnels to bring fresh air to the habitable spaces, and to exhaust air to the surface. Without a ventilation system, the air within the tunnels and stations would become stale – not appropriate for normal operations, and untenable during emergency conditions. The physical requirements for a ventilation system focus on emergency conditions, and must also allow for efficient operation during normal operations.

Ventilation is accomplished by moving air between two spaces, in this case, between the proposed stations and tunnels, and between the stations and above ground. This can be accomplished through two methods:

- Vertically, where vent intakes and exhausts are located above station and tunnel elements on the surface within a vent building and connected via vent shafts to structures on the surface. In this case, the equipment used to ventilate (the “fan plant”) can be located either on the surface, or within the tunnel/station footprint.
- Horizontally, where jet fans are used to push and pull air into the tunnels via the portals at either end. In this case, the jet fans must be physically located within the tunnel diameter.

Boston’s Central Artery tunnel uses both vent buildings and jet fans to provide ventilation to the highway tunnel system, and it is likely that a NSRL tunnel would similarly use both methods.

In normal operation, fan plants provide fresh air to passengers on platforms and that diffuses throughout the stations. In addition, the piston effect, which is caused by air being pushed through the tunnel by moving trains, would be regulated by the fan plant shafts. This type of ventilation system would be optimized for electric trains and their reduced emissions; however, in the event a diesel train needs to access the tunnel (to rescue a disabled train, for example), the ventilation system would be able to clear diesel fumes from the tunnel for a short period of time.

In an emergency, smoke would be ventilated from the tunnel by using the push-pull principle, where the fan plant at one end of the affected tunnel segment will be operated in supply mode while the plant at the other end will operate in exhaust mode in order to replace the smoke with fresh air as quickly as possible, to provide safe air to breathe along escape routes, and to maintain a tenable means of egress system for the duration of an evacuation.

Fan plants need to be located at both ends of each station, as well as along the tunnel segments. Each vent shaft requires a vent building on the surface. If real estate is available, the fan plants can be located above grade inside the vent building (as in the Central Artery tunnel). In areas with limited real estate, the mechanics of the fan plant can be placed adjacent to the tunnel or station, with a smaller building on the surface. This option is typically more expensive, due to the need to

expand excavations along the tunnel. A typical fan plant footprint (with electrical spaces for starters, transformers and controls) is approximately 75ft by 50ft. The maps in Appendix D show the possible locations where vent buildings (large or small) could be located along the alignments. The height of vent buildings would be determined by an environmental study that accounts for the location of the building, adjacent structures, wind patterns, and sensitive areas.

For the NSRL project, the number of vent buildings required to meet design needs would vary by alternative. However, in all cases, some sort of fan plant (jet fans or vent building) would be required over each portal. Each station would also require at least one, and likely two, vent buildings. The pairing of these buildings is vital in order to create directional flows of smoke away from affected passengers. The various alignments would require anywhere from six to eight vent buildings each.

5.6 Initial Alignments Considered

Initial NSRL Feasibility Reassessment studies identified a long list of multiple alignments to be examined at a high level and screened into a short list of alternatives. Five alignment alternatives were initially considered, as follows:

- **Central Artery Two-Track** – This alternative descends out of Back Bay Station at a 2.75% grade and continues to a cut-and-cover South Station underneath the Fort Point Channel east of Dorchester Avenue. The two parallel tracks share a single 41-foot-diameter bored tunnel beneath the Central Artery, serve a mined underground North Station, and cross under the Charles River to a grade-separated portal complex connecting to the northern commuter lines. This alternative is similar to the 2003 DEIR's two-track alternative and is described in more detail in Section 5.8.
- **Central Artery Four-Track** – This alternative adds two more tracks to the downtown segment of the Central Artery Two-Track alternative, with the existing Fairmount Line tracks descending into a second 41-foot-diameter bored tunnel, straightening out directly east of the tunnel from Back Bay, and serving the same South and North underground stations (plus an additional Central Station connecting to the Blue Line at Aquarium). Connections between the tunnels are at grade, and flying junctions allow all possible inbound/outbound origin/destination pairs. This alternative is similar to the 2003 DEIR's four-track alternative and is described in more detail in Section 5.8.
- **South/Congress** – This alternative descends at a 2.75% grade out of Back Bay and curves more sharply north than the Central Artery tracks while weaving into a stacked 51-foot-diameter bored tunnel. Both the underground South Station and State-Haymarket Station (a proposed alternative to North Station) are contained within the diameter of the tube, under South and Congress Streets, respectively. The northern connections are grade-separated to serve all commuter lines currently originating in the surface North Station. This alignment is described in more detail in Section 5.8.
- **Pearl/Congress** – This alternative descends at a 2.75% grade out of Back Bay, diverging horizontally into two parallel 29-foot-diameter single-track bores underneath the Fort Point Channel, with the northbound track continuing to descend until the tracks are separated by a horizontal city block. South Station comprises two underground single-track mined station boxes, and tracks converge underneath Congress Street into two stacked single-track tunnels. State-Haymarket Station and the northern portals are located in a similar location to the South/Congress alternative. This alignment is described in more detail in Section 5.8.
- **Merrimac** – This alternative begins at Back Bay and its South Station locations are identical to either South/Congress or Pearl/Congress. This two-track alignment uses stacked tracks in either two 29-foot-diameter tubes or a single 51-foot-diameter tube. Instead of connecting to the State and Haymarket MBTA rapid transit stations, North Station connects only to Haymarket and is located underneath Merrimac Street west of the current Government Center garage. This alignment was not pursued; see the following section for more details.

5.7 Short-Listing of Alternatives

Of the long list of alternatives described in the previous section, no significant barriers were identified to any of these alignments except for Merrimac. The Central Artery Two-Track alignment uses an existing highway corridor and reduces the likelihood/extent of right-of-way acquisition. The Central Artery Four-Track alignment can be accessed by the Fairmount Line and is closest to the four-track alternative evaluated in 2003. South/Congress is a shorter route and avoids conflicts with deeper roadways, waterways, and transit tunnels, especially beneath and around South Station. Pearl/Congress uses narrower single-track tubes along narrow streets.

The Merrimac alignment was not pursued due to three significant anticipated downsides:

- A prohibitively sharp (less than 720-foot radius) curve is necessary to connect Congress with Merrimac while remaining underneath the street right-of-way.
- This stretch of Merrimac between Market/New Chardon and Staniford/Causeway Streets, while as wide as Congress, is not necessarily long enough to reasonably fit an 850-foot-long underground station with passenger connections to Haymarket.

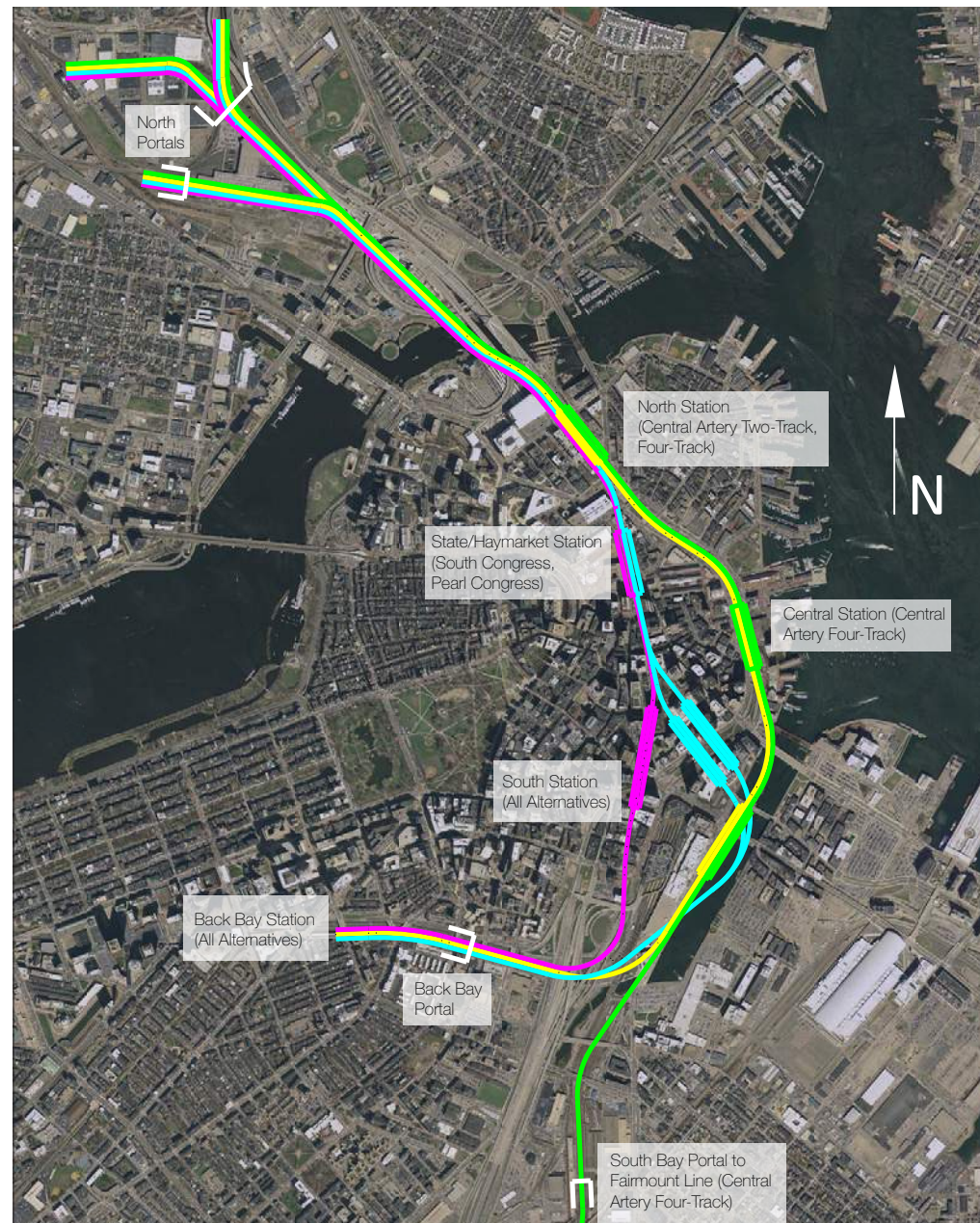


Figure 26: Short-Listed Alignment Alternatives

- In addition to these constraints, the tunnels would either require lengthening or further shifting of the alignment to avoid potential impacts to property west of Merrimac (including some MGH facilities) as the alignment climbs to connect to the existing at-grade northern commuter rail tracks.

Aside from the Merrimac alternative, each of the four other alignments has unique and promising characteristics recommending them for further analysis. An overview of each, including its tunnel diameter, number of tracks, stations provided, and station method of construction, is shown in Table 16. The alignments' routes through Central Boston are shown color-coded in Figure 26.

The next section elaborates on the alternatives above and their associated station layouts, along with tunneling methods and underground construction details unique to each alternative.

Alternative	Tracks	Number of Tunnels and Diameter	South Station	Central Station	North Station or State/Haymarket Station
Central Artery Two-Track	2	1 × 41 ft	Cut-and-Cover	N/A	Mined
Central Artery Four-Track	4	2 × 41 ft	Cut-and-Cover	Mined	Mined
South/Congress	2	1 × 51 ft	Bored	N/A	Bored
Pearl/Congress	2	2 × 29 ft	Mined	N/A	Mined

Table 16: Short List of Alignment Alternatives

5.8 Alignments and Stations

All four short-listed alignments utilize the North portals and Back Bay portal. The TBM is launched from the North portals and driven south. The Central Artery Four-Track adds the South Bay portal in order to run the Fairmount Line into the second tunnel.

The North portals require some separation via a flying junction that straddles the portal area, allowing grade-separated connectivity to all northern lines. The tunnels converge into a four-track mined cavern, with level crossovers allowing connectivity to all northern lines. One northern cavern portal carries the westernmost (“inner”) two tracks to the Fitchburg Line, which climb to reach the surface via a portal directly south of the MBTA maintenance facility building’s southwestern corner on the Cambridge/Somerville border. Another northern cavern portal carries the easternmost (“outer”) two tracks to the Lowell, Haverhill, and Newburyport/Rockport Lines, which continue northwest for another 1,500 feet, and emerge from a portal due east of the same building’s northeastern corner.

The Back Bay portal is located east of the existing Back Bay Station, between Shawmut Avenue and Washington Street. The South Bay portal is located on the Fairmount Line, just east of Widett Circle. The approximate locations of the three portals are illustrated in Figures 27 to 29.

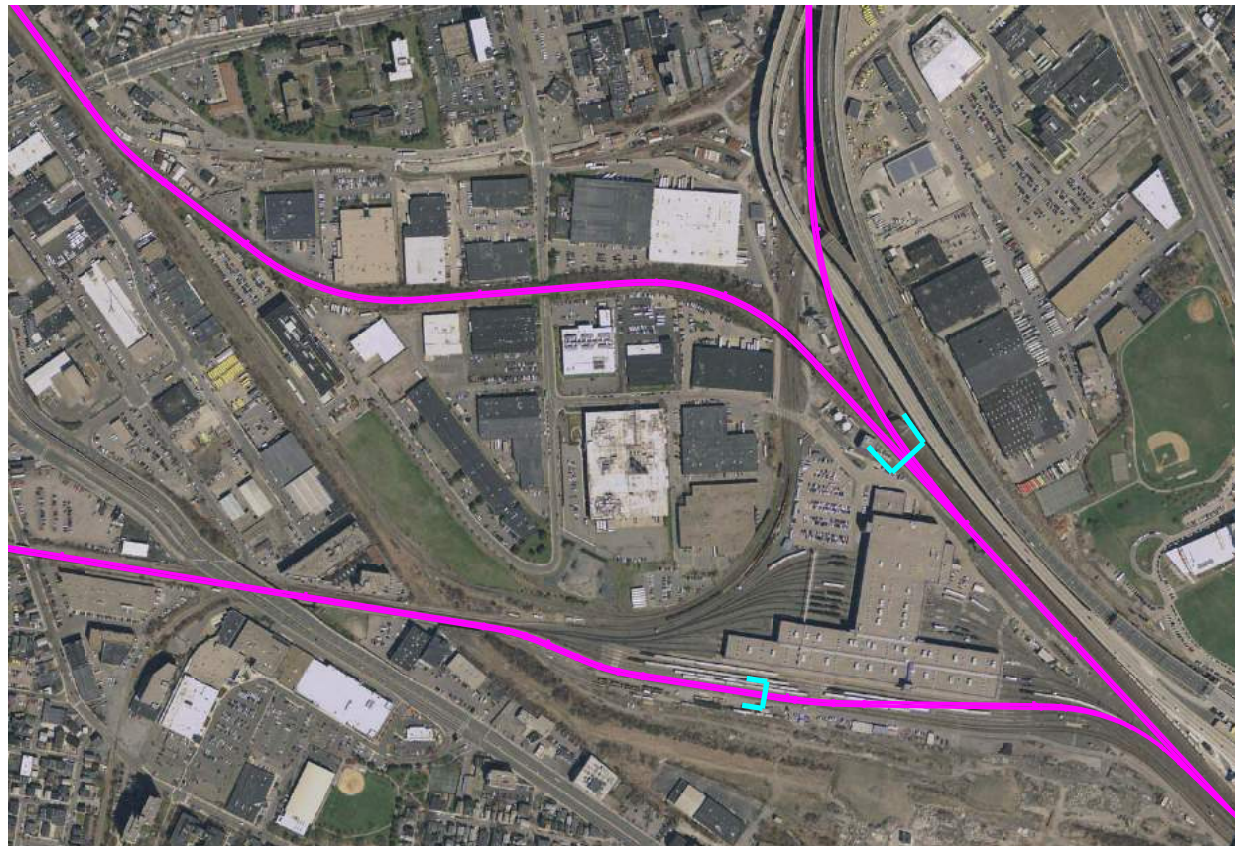


Figure 27: North Portals

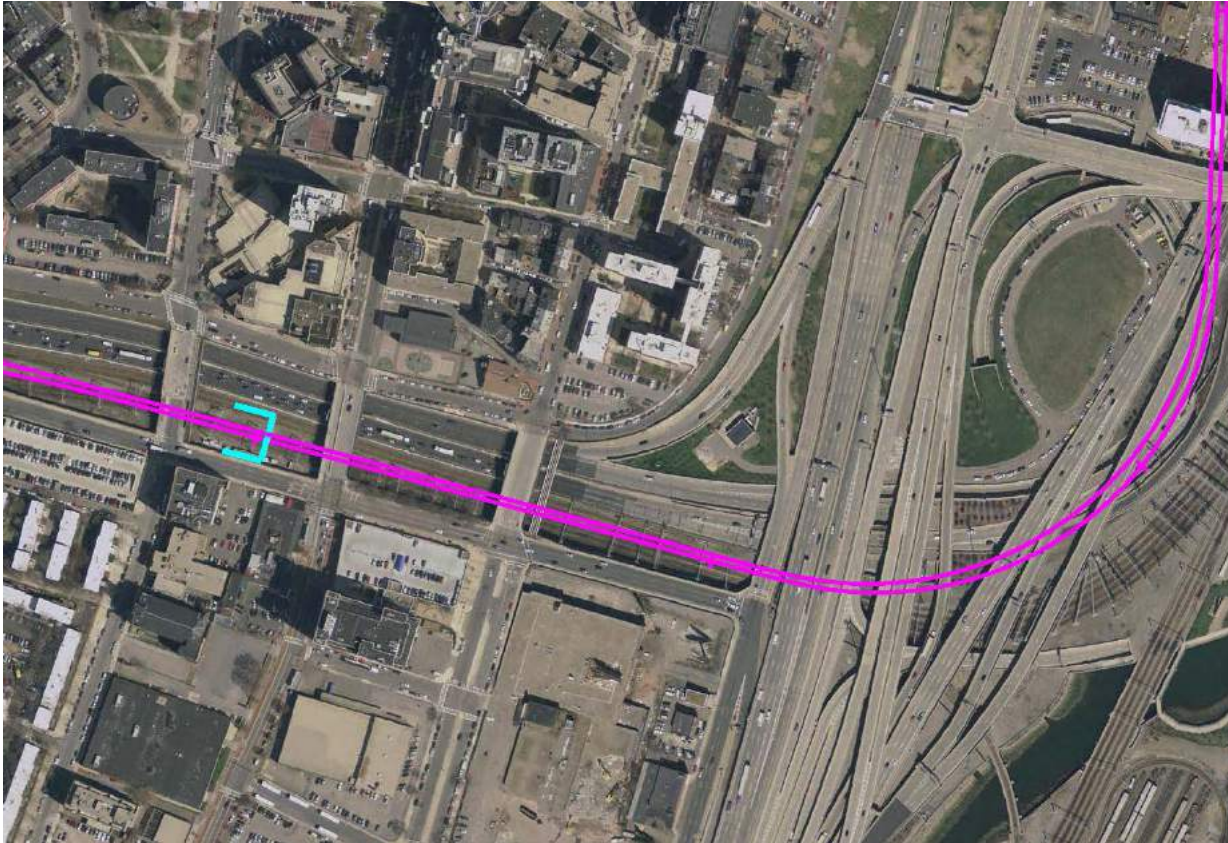


Figure 28: Back Bay Portal

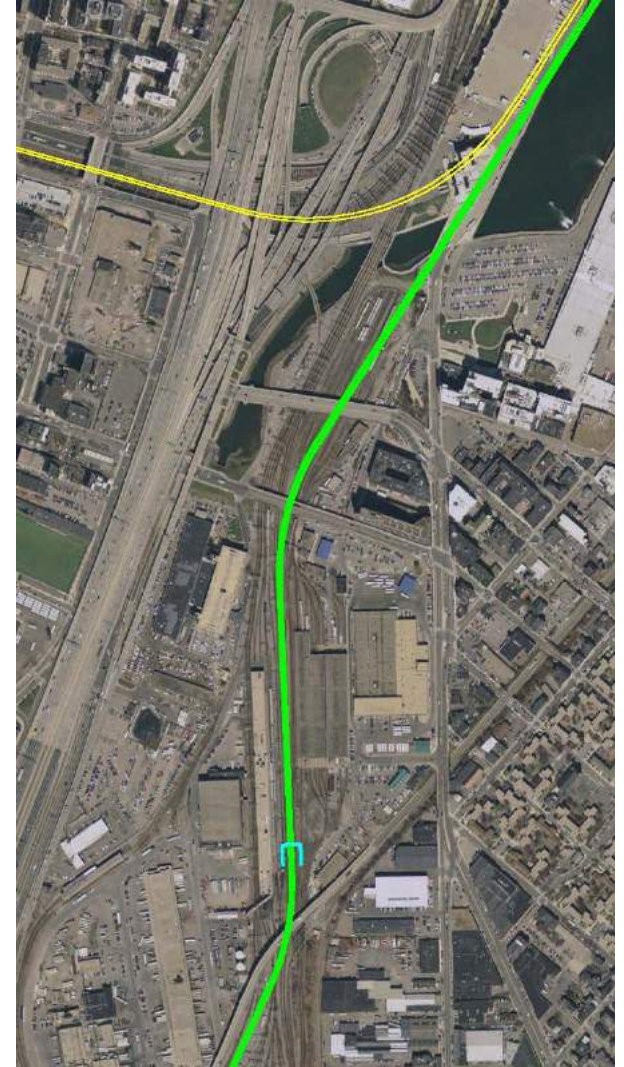


Figure 29: South Bay Portal

Central Artery Two-Track

Route and Description

Existing surface tracks from the Northeast Corridor and Framingham / Worcester Lines connect east of Back Bay Station and converge into a two-track boat section, passing over the Orange Line and descending at a 2.75% grade. Utilizing grades less than 2.75% results in the need for additional tunnel construction west and south of Back Bay Station. The tracks approach the portals in a retained cut and, once submerged, continue as mined tunnels before transitioning into a single 41-foot-diameter bored tube containing two tracks separated by 19ft (track centerline to track centerline). In the bored section, the tunnel roof (or 'crown') is approximately 30ft above the top of the rail. To provide increased separation between the new tunnel and existing structures, the tunnel crown can be lowered using a mined section when passing under the I-90 mainline tunnels or approaching the underground westbound ramp off I-90 into the South Bay Interchange. The tracks' steep grades substantially level out in the 41-foot-diameter tunnel as it runs underneath the Fort Point Channel at a depth of approximately 135ft. The two tracks also pass beneath the Red Line in the underground station area.

The underground South Station is constructed beneath the Fort Point Channel, with 1,050-foot platforms and connections to surface streets, the existing South Station headhouse, and the underground Red and Silver Line concourses. North of South Station, the alignment continues under the Fort Point Channel, passes under the Silver Line bus tunnels, and joins the Central Artery corridor, descending at a 0.5% grade to a maximum depth of 165ft. The underground North Station is beneath the Central Artery, southeast of the existing surface North Station.

Immediately north of North Station, the alignment climbs at a 2.3% grade, passing underneath the Orange Line and the Charles River. A flying junction straddles the north portal area, allowing grade-separated connectivity to all northern lines. The southbound tracks remain lower than the northbound tracks in a series of retained cuts. Beyond the northern approaches, all tracks level out and connect with the existing Fitchburg, Rockport/ Newburyport, and Lowell Lines.

Figure 30 shows the Central Artery Two-Track alignment plan and profile, starting at Back Bay.

Summary

- **Description:** Two tracks running from Back Bay portal under the Fort Point Channel, Central Artery, and Charles River to North portals
- **Alignment length (between tunnel portals):** 14,300 feet (2.7 miles)
- **Maximum alignment depth (below street level):** 165 feet
- **Tunnel type:** One 41-foot diameter (38-ft inner diameter) machine-bored tunnel carrying two side-by-side tracks
- **Construction methodology:** Cut-and-cover construction in the Fort Point Channel, mining around South Bay interchange ramps, rerouting of Worcester Line into North Station
- **Stations Include:**
 - South: Cut-and-cover, under the Fort Point Channel.
 - North: Mined underneath I-93, connecting to North Station
- **Station Platform Dimensions:** Two 16-foot-wide side platforms and one 30-foot-wide center platform
- **Station Access:** Requires dedicated headhouses on properties adjacent to stations

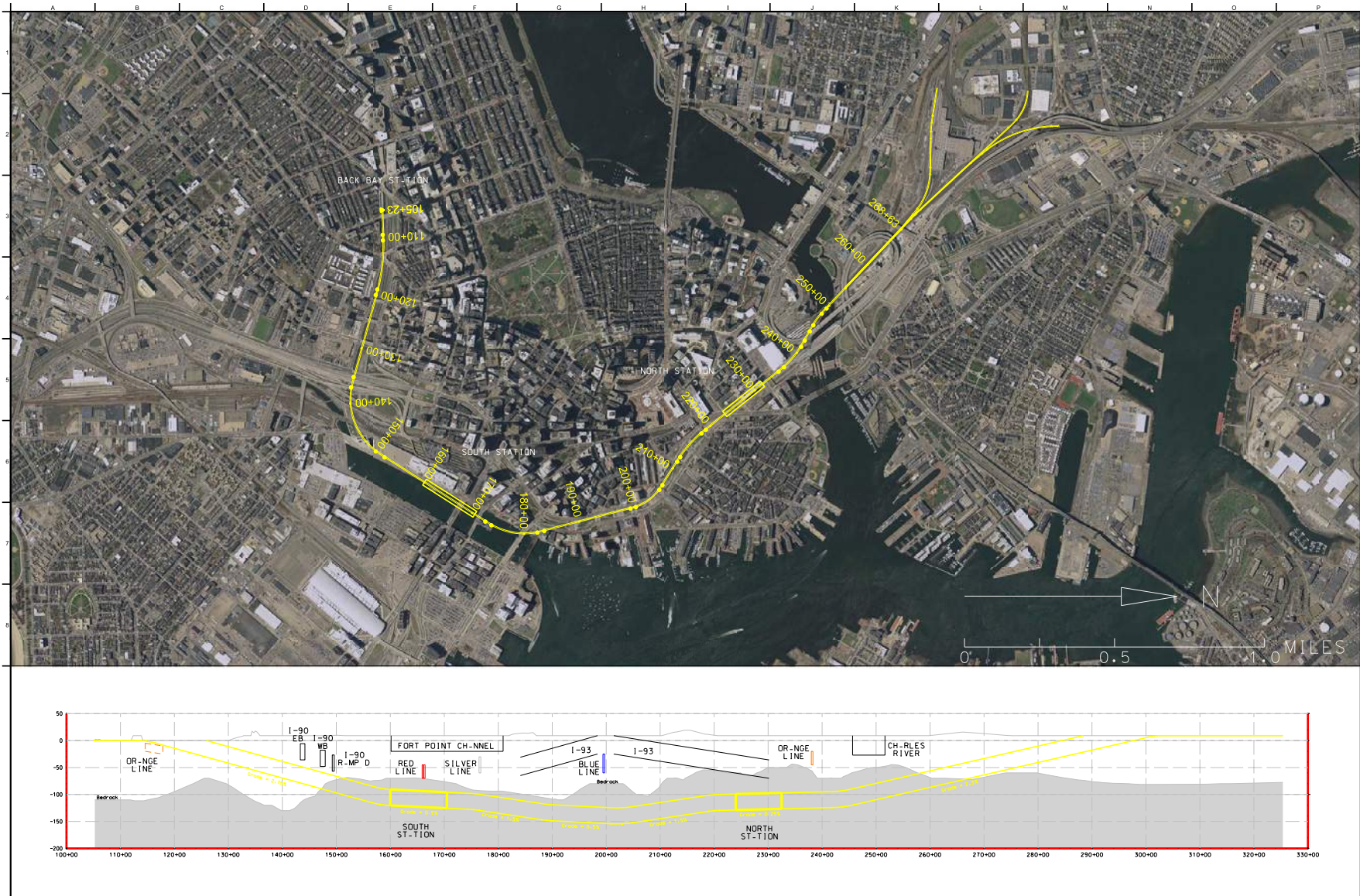


Figure 30: Plan/Profile, Central Artery Two-Track Alignment

Tunnel and Underground Construction

The Central Artery Two-Track alignment can be accommodated in a 38-foot-diameter tunnel constructed using a 41-foot-diameter TBM. The 38-foot inner diameter (ID) allows for a centerline track spacing of 19ft and a top-of-rail to top-of-tunnel distance of 30ft. These dimensions, shown in Figure 31, provide the required clearances for the train dynamic envelope, egress walkways, and mechanical systems.

The proposed South Station is built using cut-and-cover. The station's proximity to the Fort Point Channel will necessitate constructing a sheet-piled cofferdam inside the channel that will be drained to create a dry worksite for constructing the station. Upon completion of the station, the cofferdam is removed and the channel bottom backfilled to the original contours. Precedent for this approach to station construction is available from the Central Artery/Tunnel project, where sheet piling was installed in the Fort Point Channel to permit dry construction of the tunnel under half of the channel while normal tidal flushing and navigation continued in the other half of the channel.

The two 100-year-old tubes of the Red Line pass over the proposed South Station. These tubes will require underpinning, and the station excavation will likely be mined in the vicinity of the tubes.

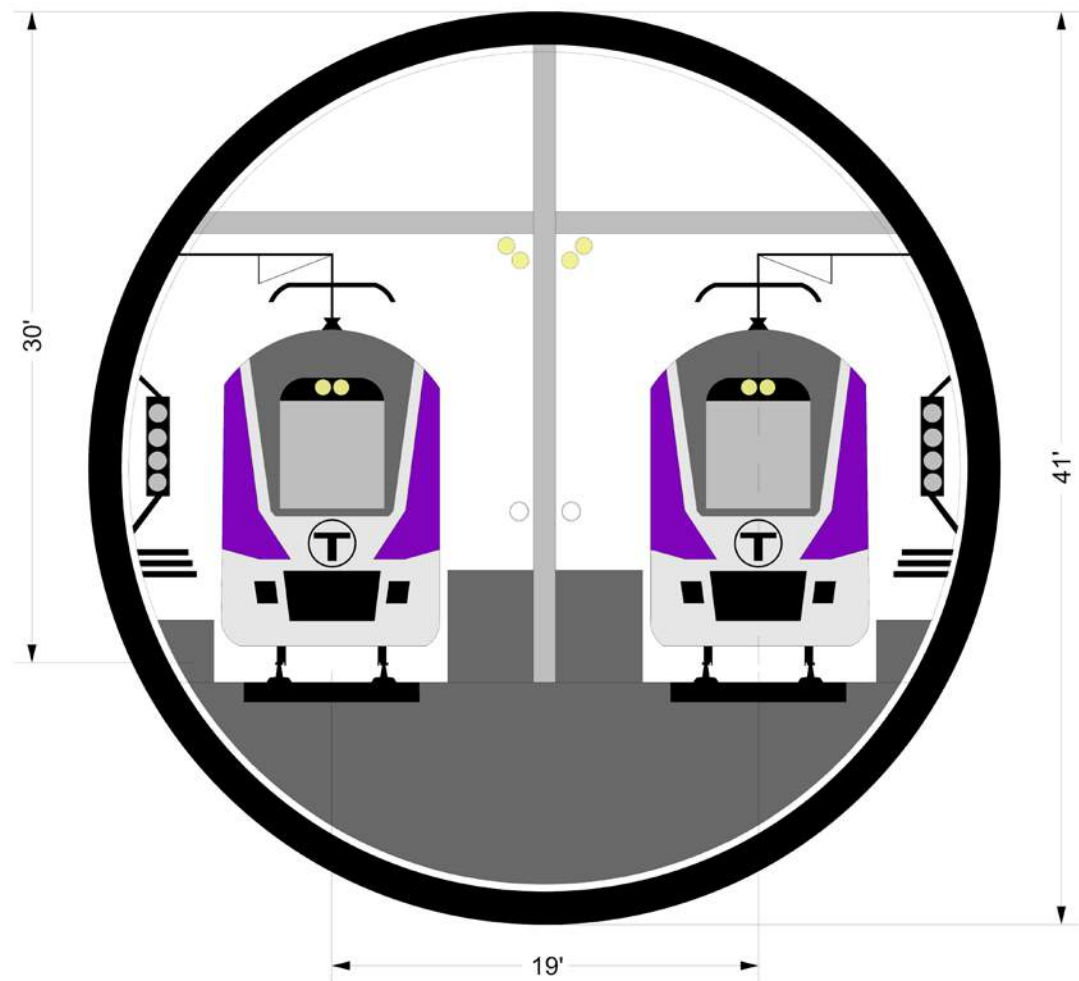


Figure 31: Tunnel Cross-Section, Central Artery Two-Track Alignment

The new underground North Station site has limited space at street level. Cut-and-cover station box construction would be disruptive to streets and buildings and mined station construction has been identified as a less disruptive approach. Mined stations are created by hand, excavating the ground area around the tunnel bore to create a wider cavern for the station area. Connections to the MBTA rapid transit lines at the new underground North and South Stations require mined pedestrian tunnels to create 15- to 25-foot-wide passenger walkways.

Innovative subsurface excavation techniques have been carried out in Boston to minimize the impacts on existing structures and roads above. The MBTA's relatively new Silver Line tunnel was constructed under Russia Wharf (three 100-year-old buildings), using a mixture of ground freezing and the New Austrian Tunneling Method (a form of mined tunnel construction). A binocular-shaped tunnel was used to minimize the required excavation volume and overall tunnel size. This precedent experience will aid in the design and construction of mined stations on the NSRL project.

Station Layout

The proposed stations for the Central Artery Two-Track alignment are configured as side platforms, fed from above by entrances at either end of the station. From these two connection points, passengers arrive at one of two large concourses spanning both tracks. The concourses allow passengers a central point of decision-making, with

access to either escalators or elevators down to the platforms. Passengers can use this area to wait for trains without creating undue congestion on the platforms. In addition, the concourse provides a line of sight down to the trains below and can assist with the wider wayfinding strategy.

The proposed underground South Station, shown in Figure 32, is reached from a connection to the existing South Station at its northern end via the Red and Silver Line concourse. At its southernmost point, South Station is reached by a combined entrance and ventilation headhouse on the eastern

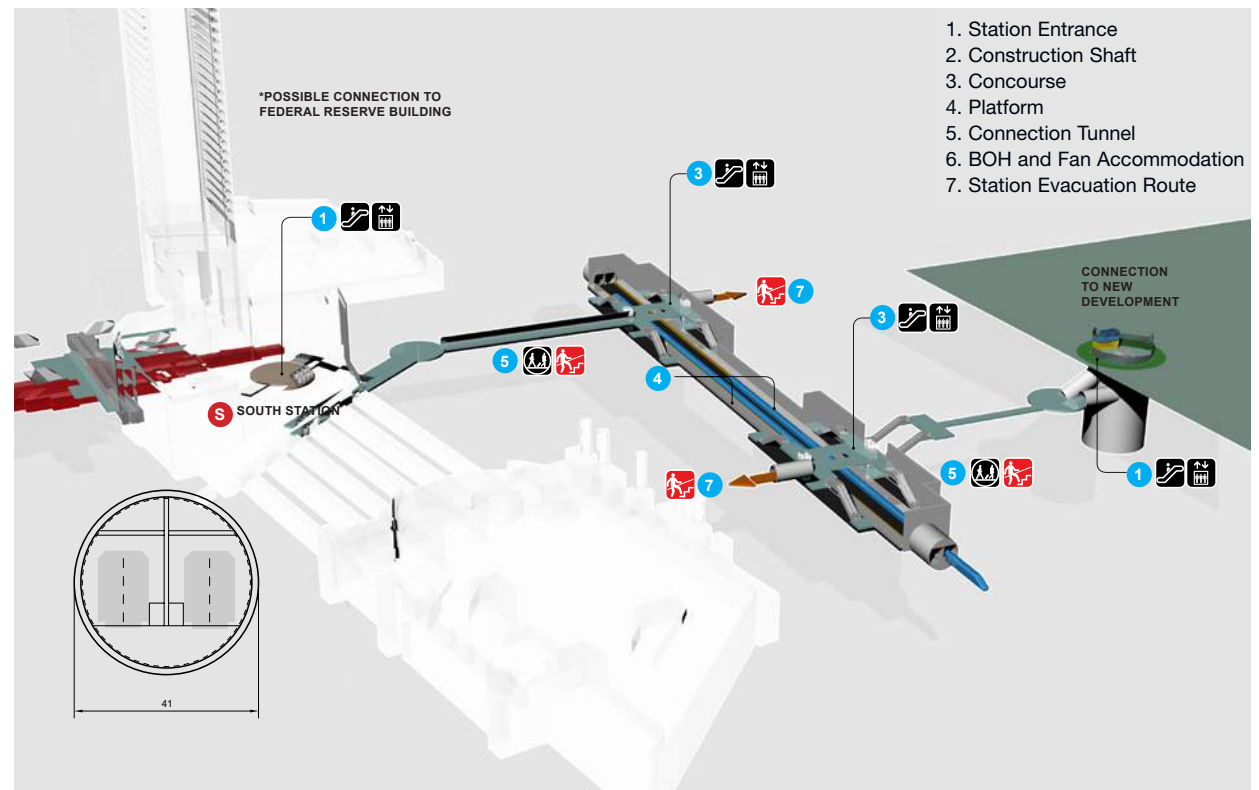


Figure 32: South Station, Central Artery Two-Track Alignment

side of the Fort Point Channel within the Fort Point District 100 Acres Master Plan. Since the proposed South Station will be built using cut-and-cover construction, there are significant opportunities to place ancillary and back-of-house space (such as the tunnel ventilation fans) into levels above the platform and below the street. Potential additional headhouse locations include the vicinity of the existing South Station.

The proposed underground North Station, shown in Figure 33, has two primary means of access for passengers: one directly adjacent to the TD Garden to the north and one at Haymarket Station to the south. Both connections are built in anticipation of future links to planned developments in those areas. The connection at Haymarket also provides access to the Orange and Green Lines. Tunnel ventilation can be facilitated via a shaft located within the parking lot at 37 Merrimac Street. Potential headhouse locations include the vicinity of the existing North Station and the Haymarket Square on one or more corners of Merrimac, Market, or New Chardon Streets.

Fire/Life Safety

The Central Artery Two-Track alignment could be designed with a hardened, fire-rated barrier between the two tracks, eliminating the need for any emergency-only exits. If this barrier is not included, emergency exits would be needed between the two stations, and between each station and the portals, as those distances are greater than 2,500ft.

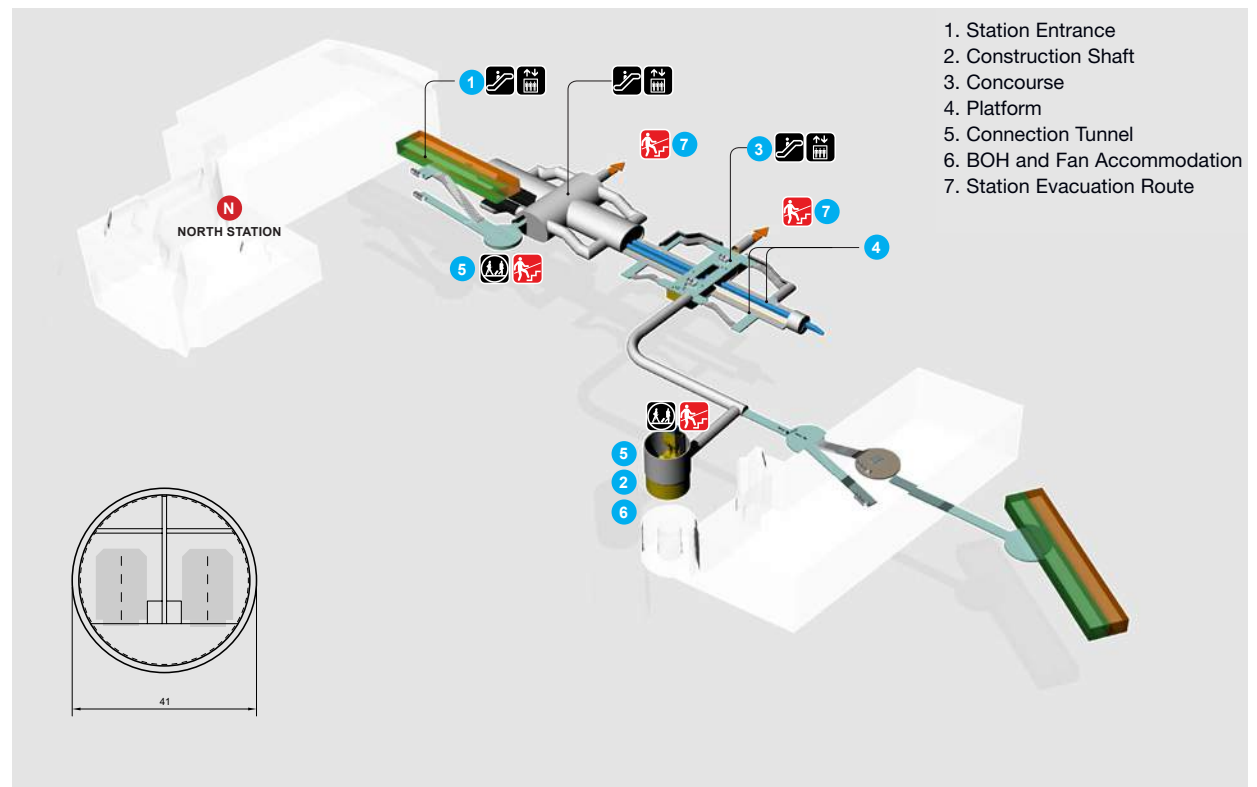


Figure 33: North Station, Central Artery Two-Track Alignment

Central Artery Four-Track

Route and Description

This alternative is comparable to the Central Artery four-track alternative proposed in 2003, with three minor differences: (1) only a single South Bay portal is included, connecting to the Fairmount Line, (2) both the Central and North Station platforms are 850ft long (the 2003 study assumed Amtrak trains would be stopping at both the underground North and South stations, and so the platforms at North Station in that study were designed to have a length of 1,050 feet), and (3) a grade-separated switch area, at or near the north portals, is proposed to allow conflict-free movements between commuter rail service in opposite directions.

Existing surface tracks from the Northeast Corridor and Framingham/Worcester Lines connect east of Back Bay Station and converge into a two-track boat section, passing over the Orange Line and descending at a 2.75% grade. Utilizing grades less than 2.75% requires additional tunnel construction west and south of Back Bay Station. The tracks approach the portals in a retained cut and, once submerged, continue as mined tunnels before transitioning into a 41-foot bored tube containing both tracks separated by approximately 19ft. In the bored section, the tunnel roof is approximately 30ft above the top-of-rail. Where the height of the proposed tunnels is constrained by existing infrastructure, overhead clearances could be lower in a mined section. Potential locations for lowering tunnel roofs includes the area under I-90

mainline tunnels or approaching the ramp from I-90, as described in the section about the Central Artery Two-Track alignment.

Tracks from the Fairmount Line descend at a 2.75% grade, curving east and entering an identical 41-foot-diameter tube. Horizontal separation between the new Fairmount Line tunnel and the tube containing Back Bay tracks is approximately 21ft, which is considered acceptable for tunnel separation at this stage of the design. All four tracks, in parallel 41-foot-diameter tunnels carrying two tracks each, pass beneath the Red Line in the station area. The station tracks are straight, on a 0.5% grade, and approximately 135ft below street level.

The new underground South and North Stations are constructed in the same manner as for the Central Artery Two-Track alternative. Central Station is proposed to be built using mined construction techniques beneath the MBTA Blue Line at Aquarium. Immediately north of North Station, the alignment climbs at a 2.3% grade, passing underneath the Orange Line and the Charles River.

Figure 34 shows the Central Artery Four-Track alignment plan and profile; the plans start both at Back Bay and at the prevailing grade on the Fairmount Line. The profile in Figure 34 gives only the vertical alignment for the Fairmount Line approach, as the Back Bay tracks are identical to the Central Artery Two-Track alternative profile (displayed in Figure 30).

Summary

- **Description:** Two tracks from Back Bay portal join two tracks from South portal, running under the Fort Point Channel, Central Artery, and Charles River to North portals
- **Alignment length (between tunnel portals):** 14,300 feet (2.7 miles) from Back Bay portal, 14,600 feet (2.8 miles) from South portal
- **Alignment depth (below street level):** 165 feet
- **Tunnel type:** Two adjacent 41-foot diameter (38-ft ID) machine-bored tunnels, each carrying two horizontally parallel tracks
- **Construction disruption:** Cut-and-cover construction in the Fort Point Channel, mining around South Bay interchange ramps, rerouting of Worcester Line into North Station
- **Stations Include:**
 - South: Cut-and-cover, under the Fort Point Channel
 - Central: Mined underneath I-93, connecting to Aquarium
 - North: Mined underneath I-93, connecting to North Station
- **Station Platform Dimensions:** Two 16-foot-wide side platforms and one 30-foot-wide center platform
- **Station Access:** Requires dedicated head-houses on properties adjacent to stations

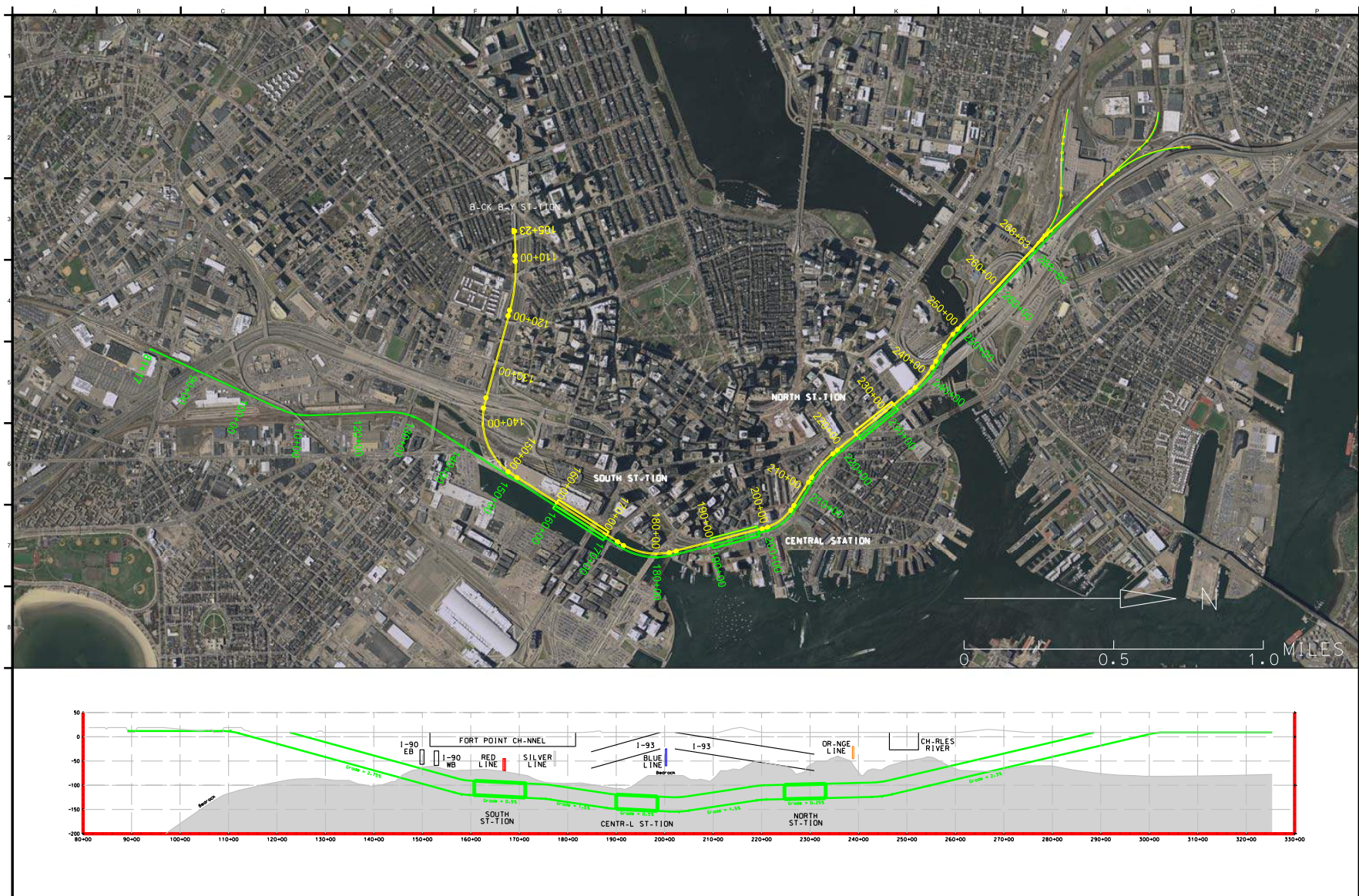


Figure 34: Plan/Profile, Central Artery Four-Track Alignment

Tunnel and Underground Construction

This alignment is very similar to the Central Artery Two-Track alignment but considers the use of two 41-foot TBMs (along the same alignment) to form two bored 38-foot ID tunnels. The internal dimensions are the same as the Central Artery Two-Track alignment and provide the required clearances for the train, egress walkways, and mechanical systems. Figure 35 is a cross-section of the parallel tunnels separated by 21ft.

The proposed South and North Stations are constructed in the same way and location as in the Central Artery Two-Track Alignment. The four-track alternative also includes a third proposed station, Central Station, which is mined. Mining has been selected over cut-and-cover due to the depth of the station and the location in the center of Downtown Boston.

Station Layout

The Central Artery Four-Track alignment station designs are consistent with those used for the Central Artery Two-Track designs, albeit with an additional centrally loaded platform to serve the two additional tracks. The stations within this alignment are wider to accommodate these additional tracks

and platform; however, the overall configuration remains the same as described in the previous section and depicted in Figures 32 and 33. As with the Central Artery Two-Track alternative, potential South Station headhouse locations include the vicinity of the existing South Station as well as the eastern bank of the Fort Point Channel, and potential North Station headhouse locations include the vicinity of the existing North Station and Haymarket Square on one or more corners of Merrimac, Market, or New Chardon Streets.

The proposed Central Station is situated south of State Street underneath John F. Fitzgerald Surface Road / Atlantic Avenue. This location has access at either end — from Aquarium Station on the north side as well as from a new headhouse entrance and ventilation shaft located at the parking lot at India Street and the John F. Fitzgerald Surface Road. Figure 36 shows the Central Station and its proximity to the Blue Line. Potential Central Station headhouse locations include Long Wharf and the sidewalks of Atlantic Ave or the John F Fitzgerald Surface Road at or near the Milk Street intersection.

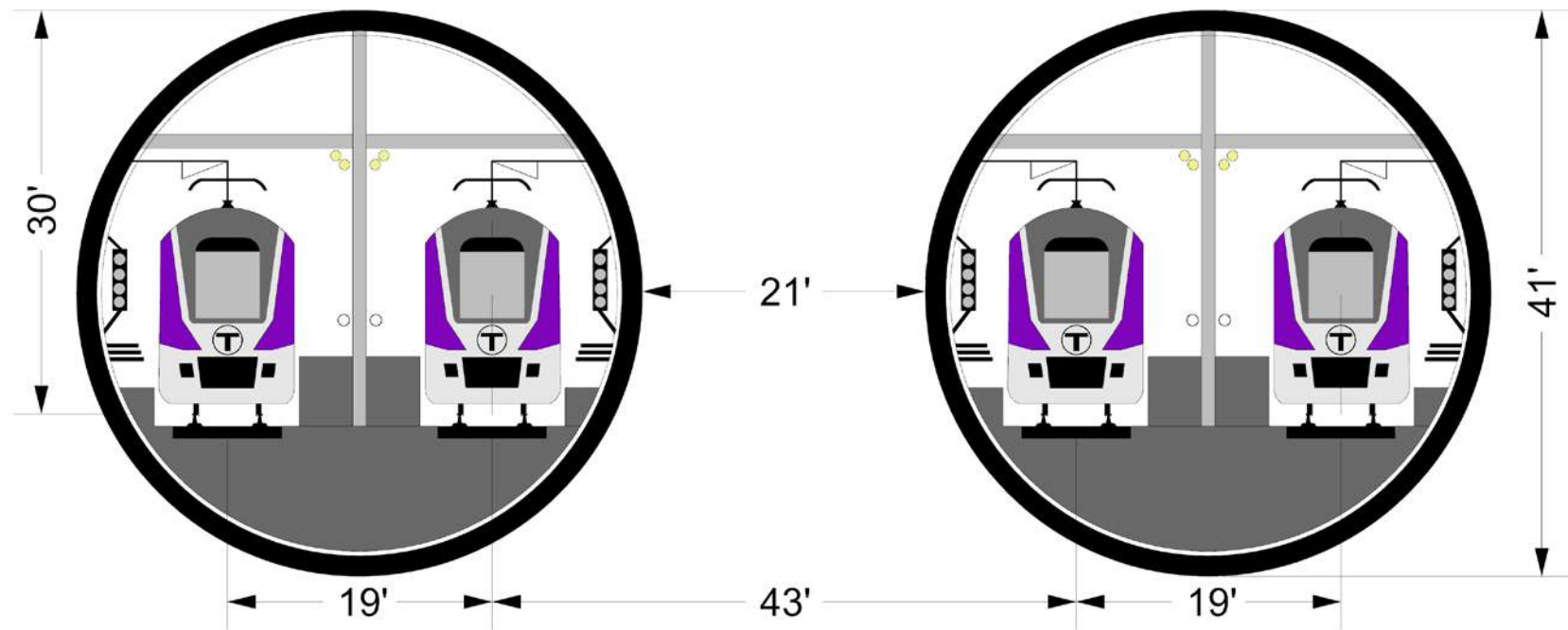


Figure 35: Tunnel Cross-Section, Central Artery Four-Track Alignment

Fire/Life Safety

The Central Artery Four-Track alignment would have two tunnels. With connections between them at least every 800ft, there is no requirement for additional emergency-only exits to the surface. A fire-rated barrier within each tunnel may also be an alternative. The decision to mine cross-passageways between the two tunnels, a fire-rated barrier along the length of the tunnel, and emergency-only exits to the surface are all subject to further review. Emergency exits to the surface become less costly for the portal portions, as the distance to the surface is shorter.

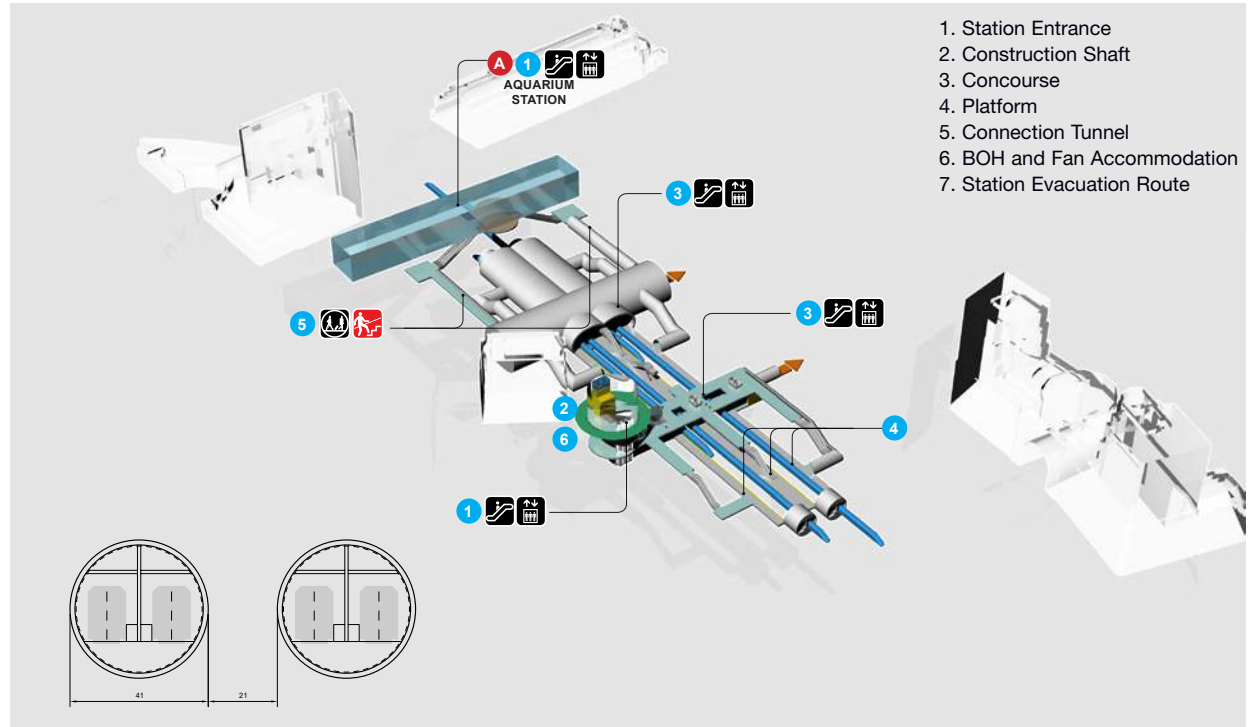


Figure 36: Central Station, Central Artery Four-Track Alignment

South/Congress

Route and Description

The South/Congress alignment is of particular interest for four main reasons:

- The alignment is shorter than either Central Artery alignment.
- The alignment does not interact longitudinally with the underground I-93 tunnel for nearly as far, or with as little vertical separation, as either Central Artery alternative.
- The stations themselves can be contained within the bored tube.
- The alignment avoids station construction beneath the Fort Point Channel, deep Red Line tubes, I-90 mainline lanes and exit ramps, and the Silver Line tunnels.

Just as in both Central Artery alternatives, existing surface tracks from the Northeast Corridor and Framingham/Worcester Lines connect east of Back Bay Station and converge into a two-track boat section, passing over the Orange Line and descending at a 2.75% grade. Utilizing grades less than 2.75% results in the need for additional tunnel construction west and south of Back Bay Station. The tracks approach the portals in a retained cut, and once submerged, continue as mined tunnels, curving sharply north with a radius of 720ft. The southbound track levels out at a depth of about 110ft while the northbound track descends under

the southbound track. In this transition, the downward grade changes from 2.75% to 0.5%, entering a large single bore with a diameter of approximately 51ft. This allows trains to operate through the curve at 25 miles per hour.

South Station platforms are 1,320ft long and constructed inside the tube beneath South Street and the Red Line tubes, one block west of the existing station headhouse. North of South Station, the alignment joins Congress Street, continuing to descend at a 0.5% grade and passing under the Blue, Orange, and Green Lines. The alignment proposes a new State-Haymarket commuter rail station replacing today's North Station, with platforms 850ft long that are also contained within the tube and connect to both State and Haymarket MBTA Rapid Transit Stations.

Immediately north of the proposed State-Haymarket commuter rail station, the alignment continues descending, realigns with the Central Artery tunnels, and begins climbing at a 2.3% grade, passing underneath the Orange Line and the Charles River.

Figure 37 shows the South/Congress alignment plan and profile, starting at Back Bay.

Summary

- **Description:** Two tracks running from Back Bay portal under South, Congress, Central Artery, and Charles River to North portals
- **Alignment length (between tunnel portals):** 13,100 feet (2.5 miles)
- **Alignment depth (below street level):** 110-160 feet
- **Tunnel type:** One 51-foot diameter machine-bored tunnel, containing two vertically stacked tracks and station platforms
- **Construction disruption:** Limited, with downtown station construction primarily off sidewalks and streets, rerouting of Worcester Line into North Station
- **Stations Include:**
 - South: Inside bored tube underneath Congress Street, connecting to South Station
 - North (State-Haymarket): Inside bored tube underneath Congress Street, connecting to State and Haymarket
- **Station Platform Dimensions:** Two 16-foot-wide stacked side platforms
- **Station Access:** Requires dedicated headhouses on properties adjacent to stations

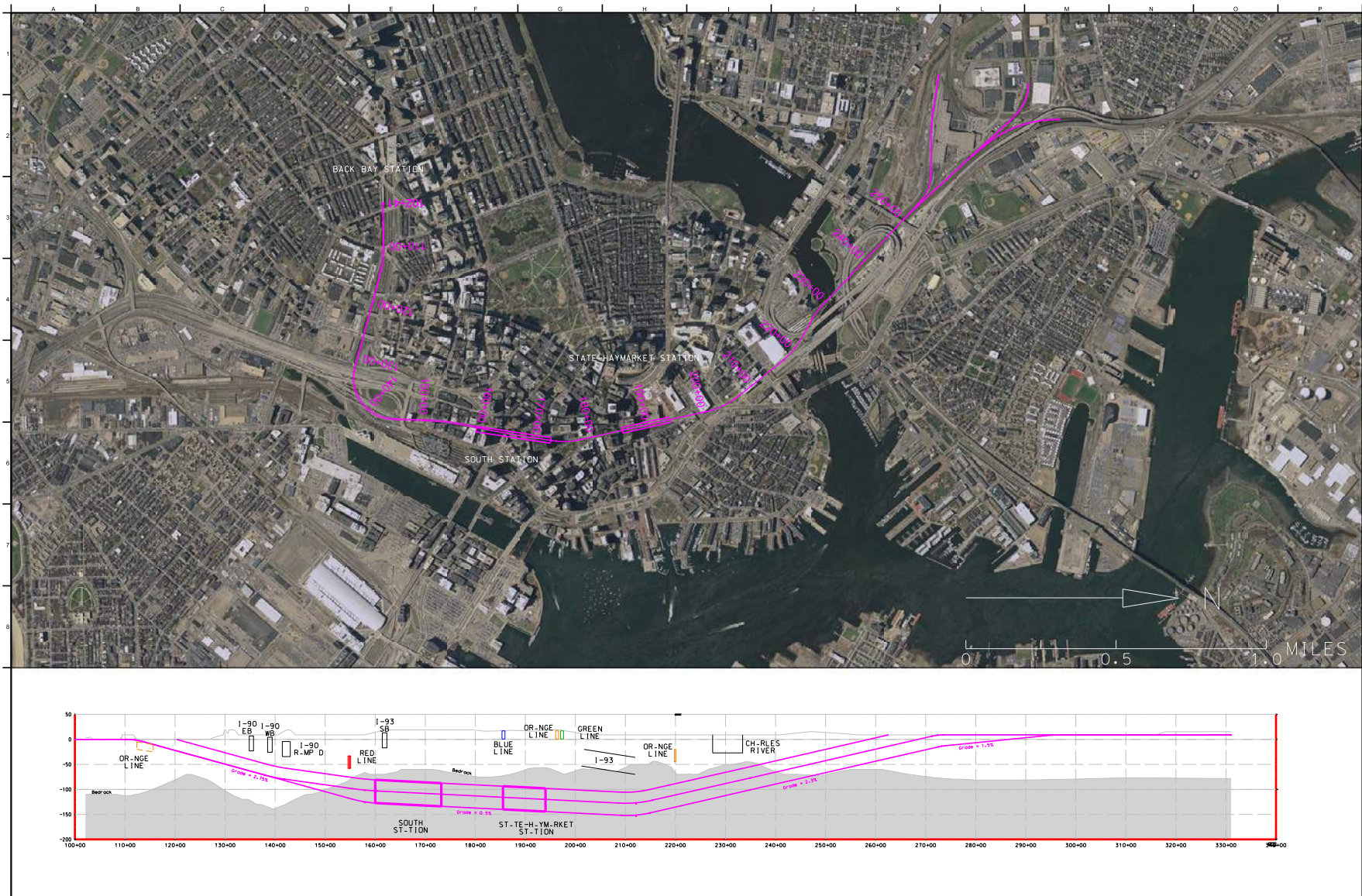


Figure 37: Plan/Profile, South/Congress Alignment

Tunnel and Underground Construction

The South/Congress alignment incorporates a single 51-foot bored tunnel, as shown in Figure 38, with the tracks stacked and station platforms within the tunnel bore. A tunnel of this configuration has been used for the subway system in Barcelona, where containing the stations within the bore and stacking the tracks has saved money and space in a congested city. Tunnels have been constructed with diameters of up to 57ft for highway tunnels in Seattle and Hong Kong. This method is increasingly being considered for transit systems as it allows all the underground space to be constructed by TBM, which is a highly mechanized and efficient operation, and avoids most of the more complex cut-and-cover or mined excavation work for the stations. As a result, both the proposed underground South Station and State-Haymarket commuter rail stations are located within the bored tunnels, with mined station entrance areas. The tunnel alternatives along this alignment use the South Street width as the limiting dimension of the tunnel.

The South/Congress alignment passes under (and offers connections with) the Red and Silver Lines at South Station and the Green, Blue, and Orange Lines at State-Haymarket.

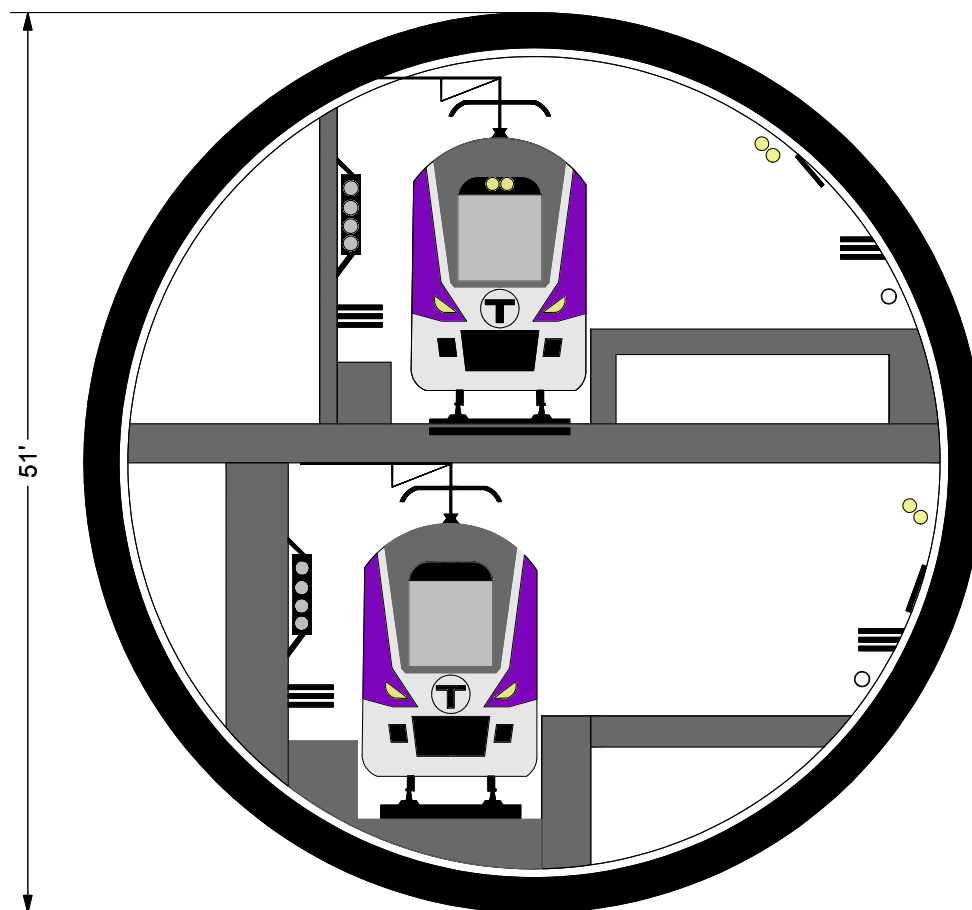


Figure 38: Tunnel Cross-Section, South/Congress Alignment

Station Layout

Both the South and State-Haymarket Stations in the South/Congress alignment are constructed within the 49-foot ID of the single-tunnel bore with stacked tracks and platform. As in other stations and alignments, vertical circulation is provided from a series of tunnels that lead to the surface. The existing South Station is connected to the new underground commuter rail station platforms via cascading stairs and escalators from the waiting room to the basement. The connection between the surface and subway tracks then descends under Essex Street, connecting to the south end of the new commuter rail station. In addition, passenger walkways can be provided within the station complex and parallel to the station platform (requiring an additional bore) to allow passenger access and evacuation. As in the other stations, the back-of-house and ancillary requirements are offloaded to the concourse and shaft locations.

The proposed South Station, depicted in Figure 39, is accessed via the Red and Silver Line concourse, within the Essex Street right-of-way. In addition, a headhouse with entrance and ventilation shafts can be located adjacent to 133 Federal Street.

A drawback to accommodating the stations within a 51-foot diameter bore is the limitation of platform widths to 16ft. Passenger demand at the proposed State-Haymarket Station is unlikely to exceed station capacity with 16-foot platforms. However, the underground South Station passenger demands

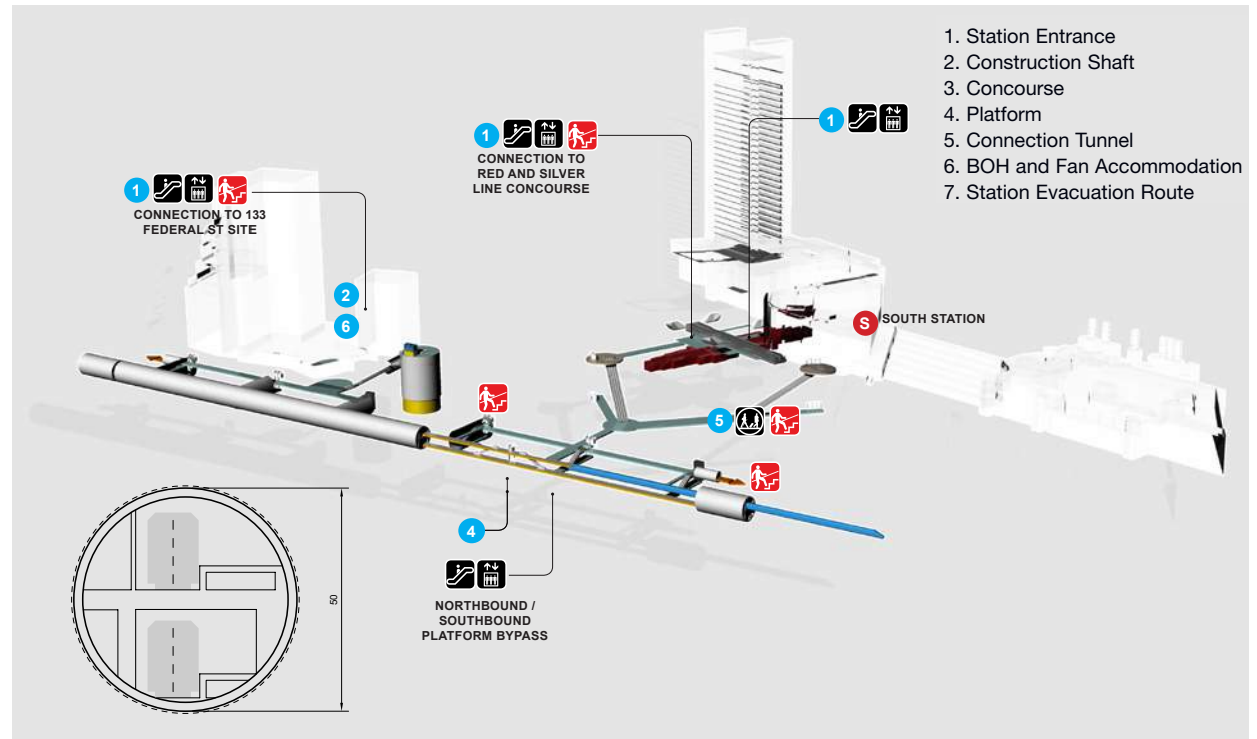


Figure 39: South Station, South/Congress Alignment

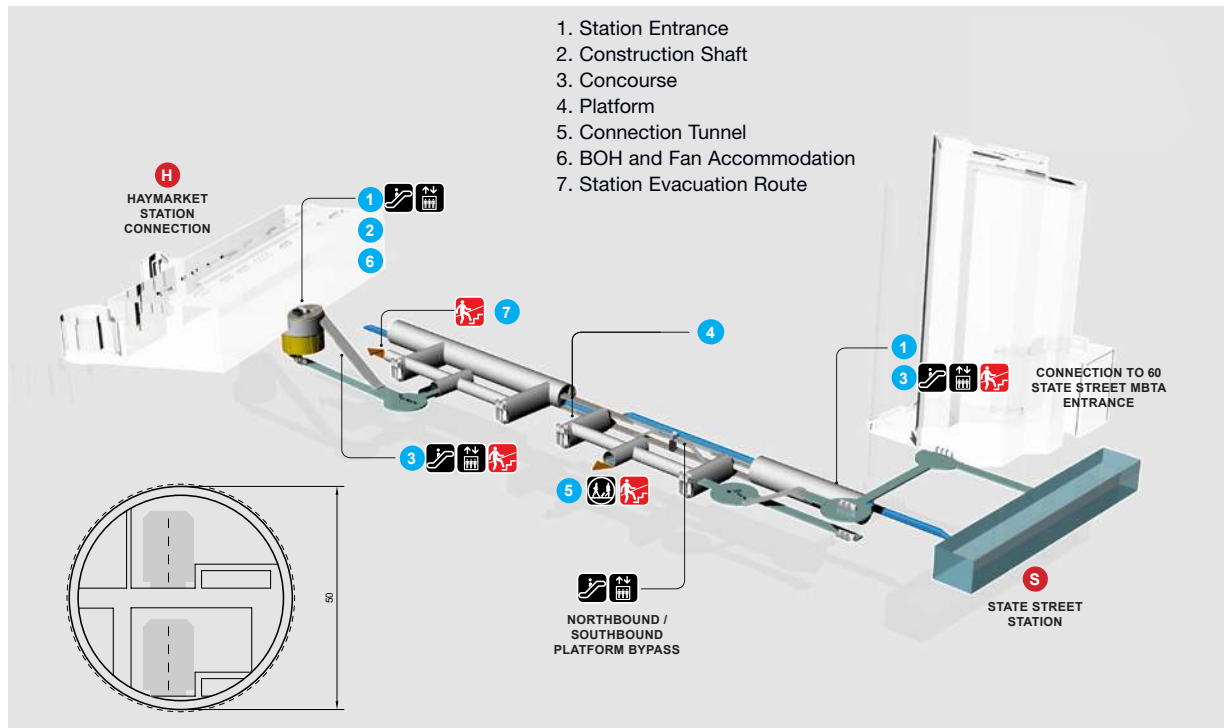


Figure 40: State-Haymarket Station, South/Congress Alignment

could result in platform overcrowding. At South Station, the platforms will be 1,320ft (400 meters) long, allowing for the staggering of MBTA trains and the spreading of passenger loads. For example, northbound trains to Newburyport/Rockport could stop at the far northern end of the platform, while trains to Lowell could stop at the midpoint of the platforms. This strategy effectively doubles passenger platform capacity at a low cost (since the station enclosure is already provided within the 51-foot tunnel).

The proposed State-Haymarket Station, shown in Figure 40, has two primary means of access, one at the rapid transit Haymarket Station to the north and another at the rapid transit State Street Station to the south. This facilitates passenger connections to the Orange, Green, and Blue Lines.

Fire/Life Safety

For the South/Congress alignment, separation of the two tracks with a hardened barrier is feasible close to the portals (when tracks are level with each other) and close to, and between, stations (where tracks are stacked). However, as the tracks transition from level to stacked between the portals and stations, this separation (and associated walkways) may not be feasible. This may result in either the need for emergency exits or for extra mining around the tunnel to allow for separation and walkways.

Pearl/Congress

Route and Description

The two-track/two-tunnel Pearl/Congress alignment is a combination of the Central Artery and South/Congress concepts. The approaches are similar to the Central Artery alternatives, but this alignment follows Congress Street and includes a new underground State-Haymarket Station between the MBTA rapid transit State and Haymarket Stations on the Blue/Orange and Orange/Green Lines, respectively.

Just as in previous alternatives discussed in this section, tracks from the Northeast Corridor and Framingham/Worcester Lines connect east of Back Bay Station and converge into a two-track boat section, passing over the Orange Line and descending at a 2.75% grade. Using grades less than 2.75% would result in the need for additional tunnel construction west and south of Back Bay Station. The tracks approach the portals in a retained cut, and once submerged, continue briefly as mined tunnels before diverging and entering single-track bores with a diameter of approximately 29ft. The southbound, higher track levels out to a 0.25% downward grade, and the northbound, lower track continues to descend until it is 43 feet deeper than the southbound track before itself transitioning to a 0.25% downward grade in turn. The tracks curve northwest under the Fort Point Channel. The new underground South Station consists of two 1,050-foot platforms, both mined, one underneath

Pearl Street and the other underneath Congress Street near Post Office Square.

North of South Station, both tracks converge underneath Congress Street and stack, with the lower (northbound) tube directly beneath the upper (southbound) tube when passing under the Blue, Orange, and Green Lines. The proposed commuter rail State-Haymarket Station, with platforms 850ft long, is mined and connects to both State and Haymarket rapid transit stations.

Immediately north of the proposed State-Haymarket commuter rail station, the lower (northbound) tracks diverge horizontally and climb to meet the upper (southbound) track. The northbound track climbs at a 1.6% grade, and once reaching the southbound track, both climb together at a 2.3% grade to the north portals, passing underneath the Orange Line and the Charles River.

Figure 41 shows the Pearl/Congress alignment plan and profile, starting at Back Bay. While the profile displays both tracks' elevation, the tracks are not parallel; at South Station, for example, the northbound and southbound tracks are separated by 250ft.

Summary

- **Description:** Two tracks running from Back Bay portal under Pearl alongside Congress (one track under each), Congress (both tracks) Central Artery, and Charles River to North portals
- **Alignment length (between tunnel portals):** 15,400 feet (2.9 miles)
- **Alignment depth (below street level):** 125-185 feet
- **Tunnel type:** Two 29-foot diameter machine-bored tunnels, each carrying a single track, transitioning from horizontally parallel to vertically stacked
- **Construction disruption:** Mining around South Bay interchange ramps, rerouting of Worcester Line into North Station
- **Stations Include:**
 - South: Parallel mined stations underneath Pearl and Congress Streets, connecting to South Station
 - North (State-Haymarket): Mined underneath Congress Street, connecting to State and Haymarket
- **Station Platform Dimensions:** Two 16-foot-wide side platforms
- **Station Access:** Requires dedicated headhouses on properties adjacent to stations

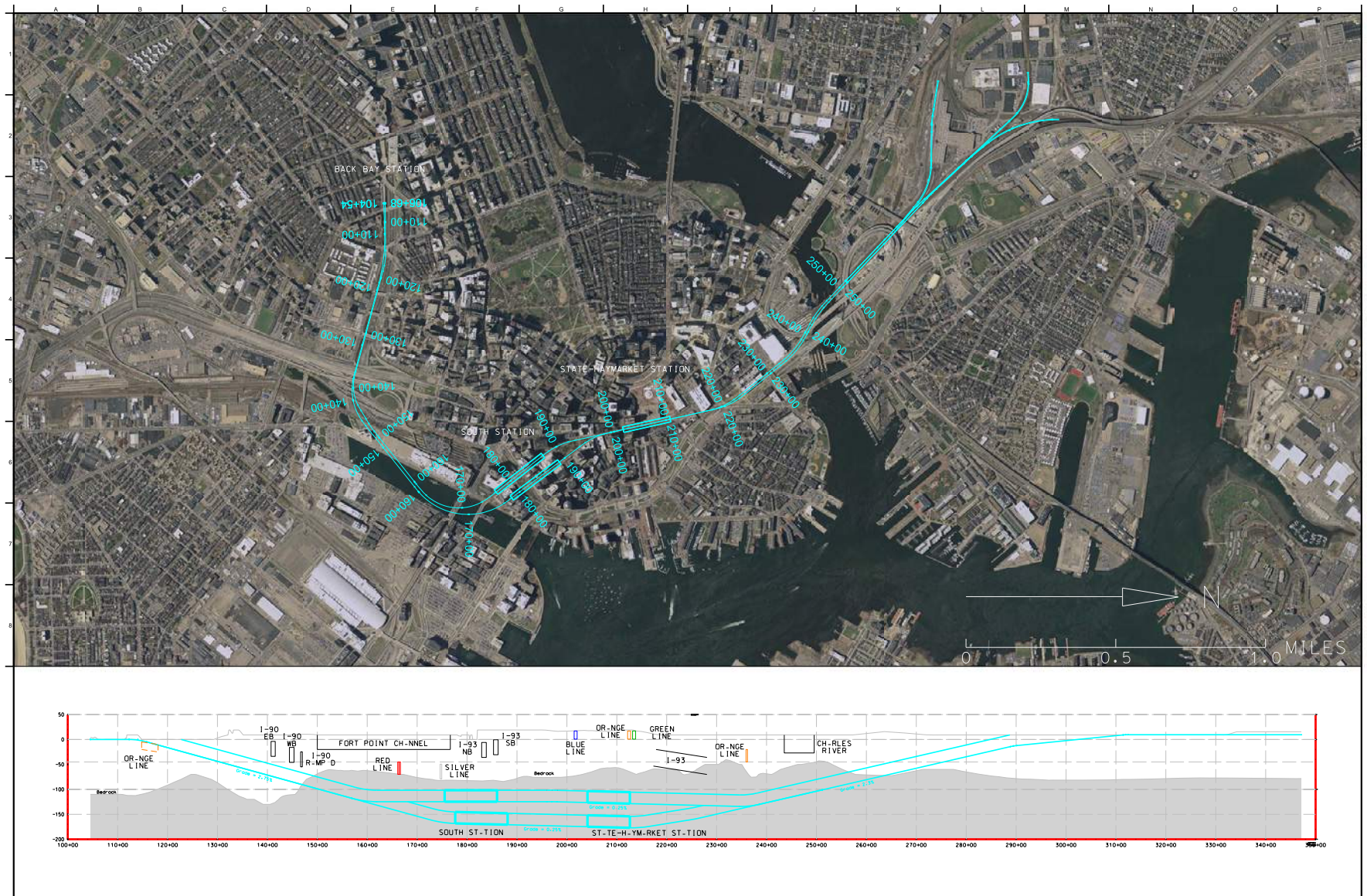


Figure 41: Plan/Profile, Pearl/Congress Alignment

Tunnel and Underground Construction

The Pearl/Congress alignment has been studied using two 29-foot-diameter TBMs launched from north of the current North Station. Due to space constraints, these two tunnels have different alignments. The tunnels follow the streets to avoid building foundations and other obstacles, and are spaced vertically for the northernmost segment of the tunnels. They are stacked north of Post Office Square, in the configuration shown in Figure 42, because Congress Street is wider north of Post Office Square than to its south; furthermore, Pearl Street is narrower along the tangent where the station is proposed. The 29-foot bored tunnels are separated by about 14ft from the top of the tunnel to the bottom of the tunnel. South of Post Office Square, the tunnels spread in both horizontal and vertical planes, as shown in Figure 43, and are a city block apart at South Station.

This alternative considers two proposed below-grade commuter rail stations: a new South Station and a new State-Haymarket Station. The proposed South Station is a mined station, similar to the Crossrail stations in London in that there is a platform tunnel for each track and concourse tunnels in the middle connecting the two. At the proposed State-Haymarket Station location, the tunnels are stacked, and the station is mined.

The station tunnels (26 to 30ft in diameter) are mined using the sequential excavation method (SEM), which was previously used in the area for the Russia Wharf tunnel (Silver Line).

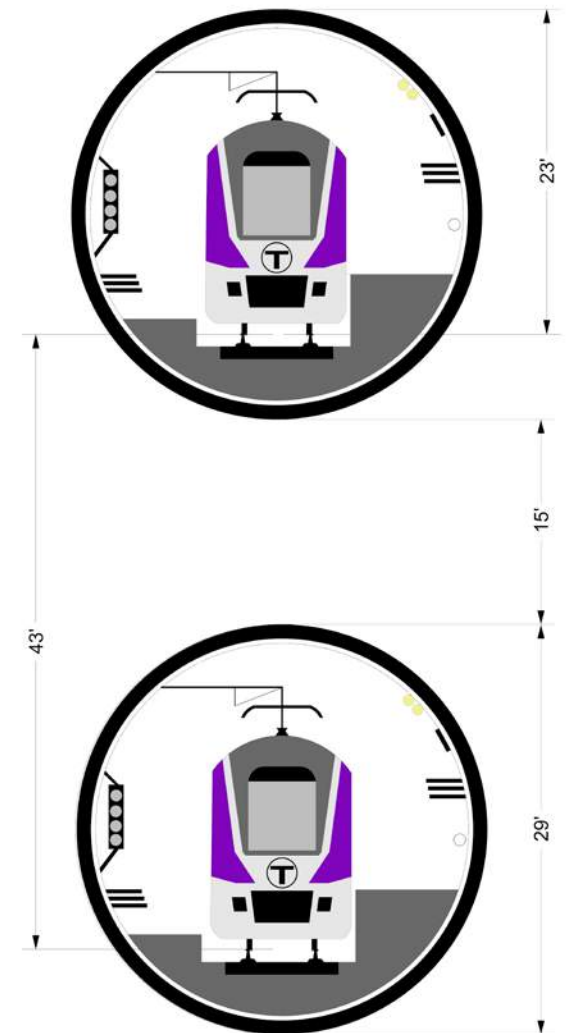


Figure 42: Tunnel Cross-Section, Pearl/Congress Alignment (Stacked)

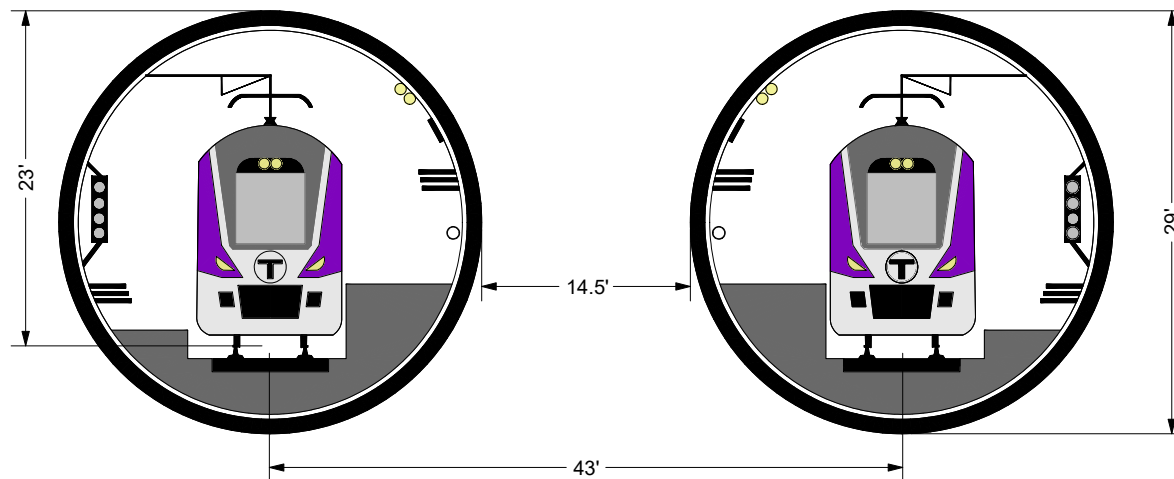


Figure 43: Tunnel Cross-Section, Pearl/Congress Alignment (Adjacent)

Station Layout

The proposed South Station, shown in Figure 44, is accessed from a connection at Post Office Square at its northern end and from the Red and Silver Line concourse and the existing surface South Station. A concourse between the two mined tracks provides a centralized passenger circulation area. Each platform is designed to host a separate passageway (parallel to the platform) as a continuous bypass that can also be used for emergency egress. Potential headhouse locations include the vicinity of Post Office Square and the blocks to the south.

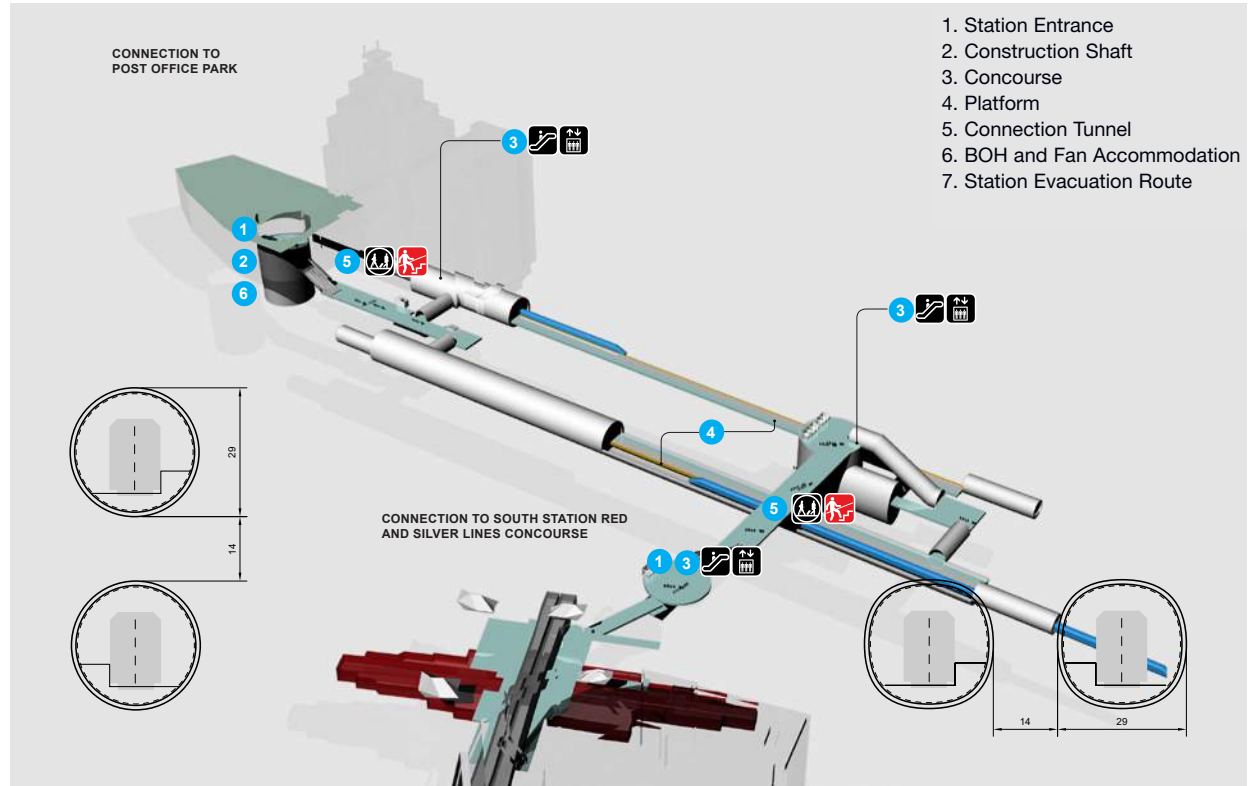


Figure 44: South Station, Pearl/Congress Alignment

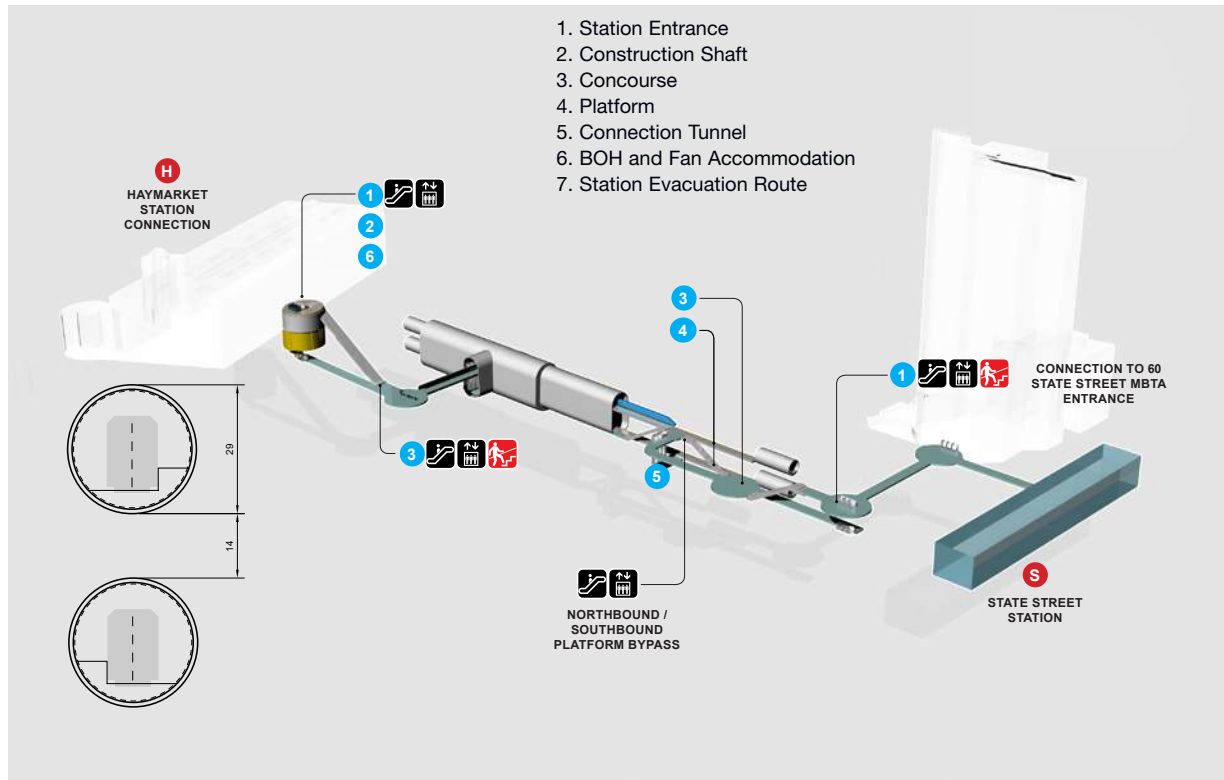


Figure 45: State-Haymarket Station, Pearl/Congress Alignment

The proposed commuter rail State-Haymarket Station, shown in Figure 45, is a stacked-track configuration with circulation adjacent to the platform to facilitate passenger movement between northbound and southbound tracks. There are two primary means of access: one at the Haymarket rapid transit station to the north and another at the State Street rapid transit station to the south, facilitating passenger connections to the Orange, Green, and Blue Lines.

Fire/Life Safety

The Pearl/Congress alignment has a similar fire/life safety design as the Central Artery Four-Track system because of the parallel tunnels. Connections are made between them at least every 800ft, so there is no requirement for additional emergency-only exits to the surface. A fire-rated barrier within each tunnel may also be an alternative. The decision to mine cross-passageways between the two tunnels, a fire-rated barrier along the length of the tunnel, and emergency-only exits to the surface are all subject to further review.

Platform Alternatives

Figures 46 and 47 show the proposed platform locations for North and South Stations for each alignment, as well as their relative location compared to the existing rail termini. Potential headhouse locations are indicated by the small circles. Table 17 shows station depths for all alignments.

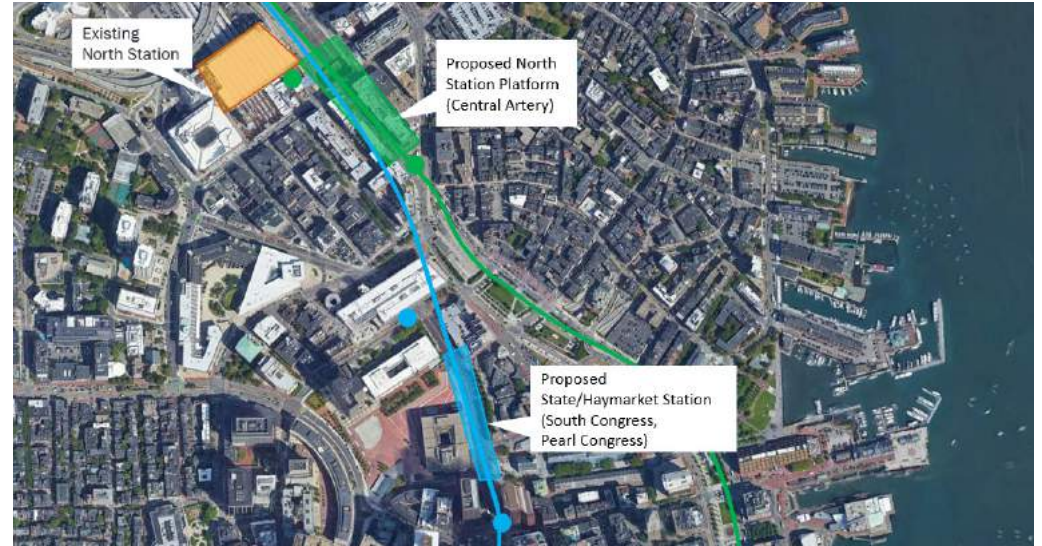


Figure 46: North Station: Platform Alternatives

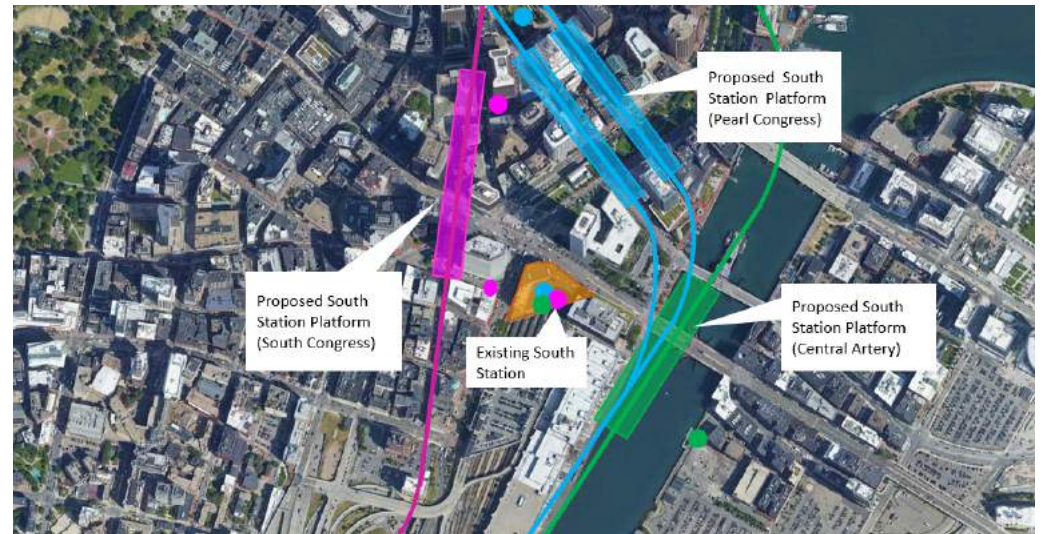


Figure 47: South Station: Platform Alternatives

Alignment	South Station Depth (ft)	North Station Depth (ft)
Central Artery	135	140
South/Congress	130	140
Pearl/Congress (Southbound)	130	135
Pearl/Congress (Northbound)	185	195

Table 17: Station Depths by Alignment

5.9 Upstream Improvements

Currently, 14 MBTA trains are scheduled from Back Bay into South Station in the peak hour and peak direction. During the same period, 13 MBTA trains arrive into North Station.

Both systems are using the full existing capacity of their respective track infrastructure. To allow a more efficient use of the NSRL tunnel, modest upstream improvements to the rail network outside of the tunnel, both north and south, will allow another three trains from the south and four trains from the north to access the tunnel. This allows for a total of 16 to 17 trains (per hour, per direction) to access the NSRL tunnel under the two-track options. The four-track alternative can only allow for an additional four trains per hour, because of the limitations of the northern system to accommodate further trains from the southern system.

To realize these increases in train movements, operational and capital improvements are required on the existing commuter rail system. At this level of scheduled service, the NSRL will be operating at about 80 to 85% of its potential capacity (assuming Amtrak operates two trains per hour, per direction in the tunnel).

The following upstream improvements and interventions are necessary to increase train movements and levels of service, as well as serve the following priorities:

- Remove conflicts between train movements
- Provide adequate platform capacity and minimize bottlenecks at stations
- Reduce train headways between signals
- Reduce headways between trains traveling on the same single-track sections (e.g., through reducing headways between trains traveling through the same junctions, or providing sidings at key locations)
- Increase capacity on currently single-track portions of the network
- Reduce turnaround times at terminals

The full list of improvements and interventions for each service alternative proposed is included as Appendix B.

5.10 Construction/Operational Impacts

Every alternative includes significant construction impacts to existing operations and requires temporary terminations, reroutings, and other measures during construction. The following service changes required to complete Back Bay portal works are among the most impactful:

- Temporary rerouting of some or all Providence, Stoughton, and Franklin Line commuter rail service via the Fairmount Line into South Station.
- The Fairmount Line would require electrification if Amtrak service into South Station is run via this line during construction.
- Limited single-tracking from Back Bay into South Station, impacting Amtrak and the Needham Line.
- Termination of the Worcester Line west of Back Bay, unless a viable rerouting (e.g., via the Grand Junction Line into North Station) is identified.
- Potential rail replacement routes on buses running from Back Bay into the Financial District.

There will be other service delays and interruptions as the north portal grade separations are constructed, but these will likely be less severe than the Back Bay–South Station impacts.

The placement of new tunnel infrastructure within an urban environment poses some challenges, with potential impacts on streets, subways, utilities and foundations. Accommodating station headhouses may cause some disruption at the surface level, and in some cases, require the taking of property.

In terms of tunneling methodologies, cut-and-cover tends to have major surface impacts, requiring the complete excavation of the tunnel route and the re-routing of streets and utilities while work is being undertaken. Tunnel boring, on the other hand, has a minimal impact on the surface but requires a staging area for the launch of the TBM. Both cut-and-cover and tunnel boring can cause concerns with building settlement (the buildings adjacent to the cut-and-cover trench or the buildings directly above the tunnel bore) and the settlement/relocation of utilities. Using TBM to bore tunnels for the NSRL alignments, while a more expensive method, has fewer surface impacts than excavating the tunnels through cut-and-cover.

6. Cost Estimates and Analysis



Photo Source: Charlotte / Unsplash

6. Cost Estimates and Analysis

6.1 Cost Estimating Methodology

Estimates for the NSRL project follow industry best practices for large public transportation programs. The estimates are classified in accordance with the Association for the Advancement of Cost Engineering International (AACEi) Estimate Classification System. The System characterizes the level of design and of construction detail and establishes the appropriate ranges of contingency corresponding to these levels of detail.

The cost estimates within this report are not intended to set the final budget for the proposed project, but to allow for comparison of the alignments. The following parameters and guidance form the basis for the cost estimate:

- All costs are reported in 2018 US dollars and escalated to Quarter 1, 2028, the year that has been estimated as the midpoint of project construction. See Appendix E for more details.

- The cost analyses were performed in conjunction with the engineering and design process, and are based on the information available for each alignment, as well as key constructability issues identified by the project team.
- Research was conducted to determine comparable projects to NSRL. Individual benchmarking exercises were developed for key engineering and construction components (e.g., tunnel and station excavations). Refer to Appendix E for further details on the estimating methodology.

Definitions of the terms used in this chapter, such as indirect costs, additional costs, and soft costs, can be found in Appendix E under the Cost Methodology section.

6.2 Organization of the Cost Estimate

The costs are reported under general headings – stations, tunnels, etc. – for each of the following alternatives:

- The South Station Expansion (No NSRL) alternative
- The two-track tunnel alternatives (Central Artery Two-Track, South/Congress, and Pearl/Congress alignments)
- The four-track tunnel alternative (Central Artery Four-Track alignment)

There are two distinct components to the costs for each alignment – Tier 1 and Tier 2 costs.

Tier 1 costs capture the infrastructure costs needed to create the physical north-south rail connection within each alternative. Tier 1 costs do not include additional infrastructure in investments and rolling stock to achieve greater capacity increases beyond those achieved by the basic connection of the northern and southern rail systems.

Tier 2 costs capture the additional investments necessary to increase rail service to the levels defined in Section 4.3. Tier 2 items include upstream/downstream system improvements and additional trackwork, vehicles, and layover facilities.

There is a third category, Tier 3 costs, that is not included in the NSRL costs. This category encompasses potential project elements that were identified and costed out but not selected for inclusion in this Feasibility Reassessment (either because they were unnecessary for MBTA and would primarily benefit Amtrak, or because their costs were judged to be too high for the limited benefit they would provide). These project elements include electrification of the Lowell and Fairmount Lines, and works to widen Salem Tunnel. Details of these project elements and their costs can be found in Appendix E.

South Station Expansion (No NSRL) Alternative Costs

The total probable project costs for the South Station Expansion (No NSRL) alternative is approximately \$1.7bn (\$2.5bn in 2028) and include the following works, consistent with the South Station Expansion project scope* and allowing for service increases to North Station:

- Dorchester Avenue improvements: a half-mile of roadway improvements, including a new cycle track, a harborwalk for pedestrians, landscaping enhancement, realignment and reconstruction of the roadway (also includes reconstruction of a portion of the adjacent seawall), and improved stormwater management
- South Station headhouse: includes new amenities and better circulation for an improved passenger experience and improved multimodal connections
- South Station Expansion trackwork: additional platform capacity, extensions and modifications to the existing platforms, new elevated pedestrian concourse, all associated trackwork, and an overhead catenary system for the new platform tracks.

- Layover facilities – Widett Circle: includes a new transportation building; facility expansion to accommodate up to 26 additional trains, improvements to existing parking lot; drainage improvements, and all associated trackwork
- Layover facilities – Readville: includes a new transportation building, facility expansion to accommodate five to seven additional trains, improvements to the existing parking lot, drainage improvements, and all associated trackwork
- An allowance of \$400m (\$565m in 2028) has been made to account for all real estate acquisition costs and required relocation expenses related to right-of-way purchases

Total project costs are available in Table 18. Refer to Appendix E for the detailed estimate.

**While the separate South Station Expansion project itself generated cost estimates, independent estimates for its project components were developed as part of this NSRL Feasibility Reassessment.*

Tunnel Alignments

The total probable project costs for the three two-track tunnel alignments range from \$6.1bn to \$7.6bn

(\$8.6bn to \$10.7bn in 2028). The probable costs for the four-track tunnel alignment are \$12.6bn (\$17.7bn in 2028). All tunnel alignments include the following works:

- Tunneling works segregated by construction methodology, based on alignment constraints and conceptual tunnel design (using TBMs or mined); including tunnel interior fit-out (assumed to be concrete) and allowances for tunnel systems (drainage, ventilation, fire protection, systems, power, and lighting)
- Station works segregated by construction methodology (within the TBM bore, cut-and-cover, or mined), including station fit-out and finishes for concourses, platforms, connecting tunnels, access shafts, elevators/escalators, and station systems
- Trackwork, including all civil works required for at-grade track; direct fixation track for the below-grade portion of the alignment, including rail, ties, clips, and pavement structure; allowance for special trackwork; and electrification to feed the traction power and signaling systems
- Portal works segregated by geographical location (North portals and Back Bay portal), including all civil works associated with the grade separations

(retaining walls, excavations), track reconstructions, elevated structures for the North portals, electrification of the NSRL tunnel, and extension into the existing lines, as follows (and illustrated in Figure 48):

- Fitchburg Line: electrification from NSRL tunnel to Porter Square Station
- Lowell Line: electrification from NSRL tunnel to West Medford Station
- Haverhill Line: electrification from NSRL tunnel to Malden Center
- Rockport Line: electrification from NSRL tunnel to Chelsea Station
- Allowances as follows:
 - Underpinning works: based on 3-D models that identified areas of conflict with existing structures and buildings, segregated by geographical area
 - Allowances for roadway reconstructions throughout the project
 - Allowances for utility relocations
- Layover facility (no specific location identified) based on the Readville layover facility's total cost

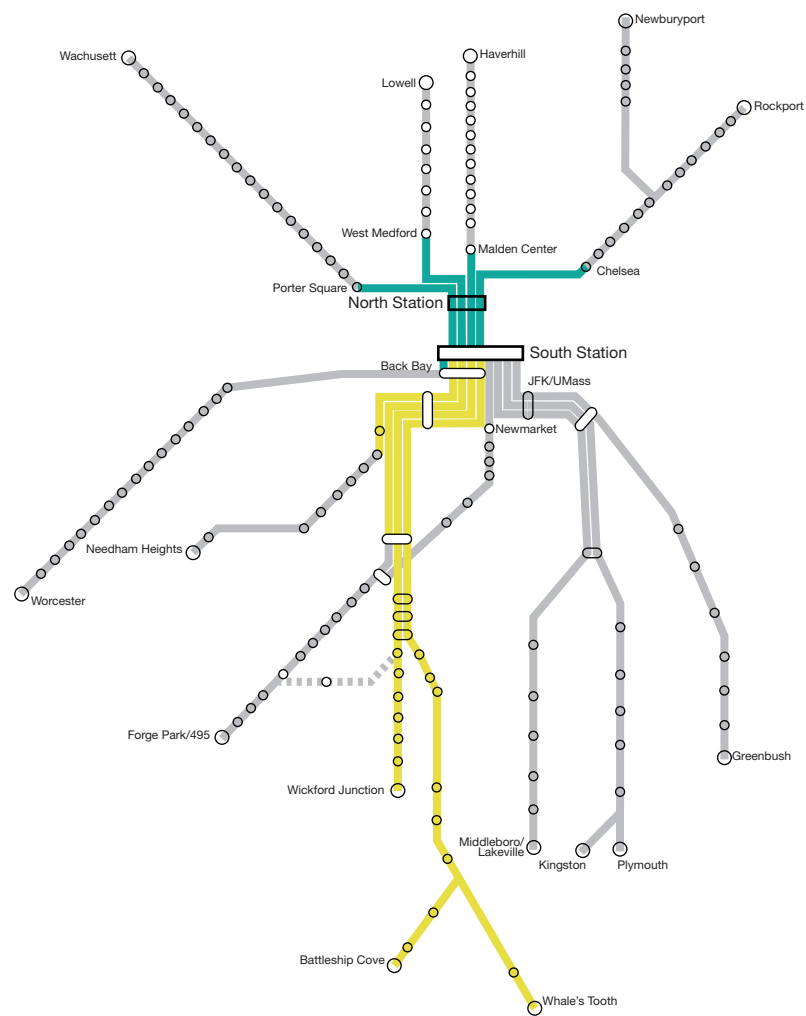


Table 18 summarizes the total project costs for all alternatives. Refer to Appendix E for the detailed breakdown of the estimate.

Figure 48: Proposed Electrification of the MBTA Commuter Rail system

	No NSRL	Two-Track			Four-Track
Description	South Station Expansion Costs (\$)	Central Artery Costs (\$)	Pearl/Congress Costs (\$)	South/Congress Costs (\$)	Central Artery Costs (\$)
Dorchester Avenue Improvements	28,008,200	-	-	-	-
South Station Headhouse	234,712,500	-	-	-	-
Tunneling Works	-	1,002,782,600	1,181,777,700	1,344,447,400	2,384,042,400
Station Work	-	445,754,000	844,092,800	264,225,400	1,345,794,100
Trackwork	181,226,500	104,162,200	100,345,800	92,519,200	207,116,800
Portal Works	-	672,737,700	672,737,700	672,737,700	687,697,700
Allowances	-	145,491,000	168,538,000	162,367,500	150,684,200
Layover Facilities	163,288,800	33,973,400	33,973,400	33,973,400	33,973,400
Total Direct Cost	607,236,300	2,404,900,900	3,001,465,400	2,560,270,600	4,809,308,600
Indirect Costs	151,809,000	751,642,700	927,633,100	840,234,800	1,559,933,600
Subtotal D + I	759,045,000	3,156,543,600	3,929,098,500	3,400,505,400	6,369,242,200
Contractor's Contingency (10%)	75,904,500	315,654,400	392,909,900	340,050,600	636,924,300
Subtotal	834,949,500	3,472,198,000	4,322,008,400	3,740,556,000	7,006,166,500
OH & P (12%)	100,194,000	416,663,800	517,641,100	448,866,800	840,740,000
Total Construction Costs	935,143,500	3,888,861,800	4,840,649,500	4,189,422,800	7,846,906,500
Design / Engineering (9%)	84,163,000	349,997,600	435,658,500	377,048,100	706,221,600
Total DB Price	1,019,306,500	4,238,859,400	5,276,308,000	4,566,470,900	8,553,128,100
Soft Costs (15%)	152,896,000	635,829,000	791,446,200	684,970,700	1,282,969,300
Subtotal incl. Soft Costs	1,172,202,500	4,874,688,400	6,067,754,200	5,251,441,600	9,836,097,400
Tunneling Risk (40%)	N / A	867,221,200	1,022,018,900	1,154,049,800	2,061,755,000
Civil Works Risk (25%)	175,830,400	405,995,300	526,906,100	354,947,600	702,256,500
Subtotal Risk Costs	175,830,400	1,273,216,500	1,548,924,900	1,508,997,400	2,764,011,500
Subtotal Project Costs	1,348,032,900	6,147,904,900	7,616,679,100	6,760,439,000	12,600,108,900
ROW	400,000,000	N / A	N / A	N / A	N / A
Total Project Costs Qtr. 1 2018 USD	1,748,032,900	6,147,904,900	7,616,679,100	6,760,439,000	12,600,108,900
Escalation to 2028 (41%)	717,740,200	2,524,322,200	3,127,399,000	2,775,827,900	5,173,589,100
Total Project Costs Qtr. 1 2028 USD	2,465,773,100	8,672,227,100	10,744,078,100	9,536,266,900	17,773,698,000

Table 18: Summary of Tier 1 Project Costs for All Alternatives

*The South Station Expansion (No NSRL) Alternative corresponds to a Level 3 of the AACEi accuracy matrix, and the tunnel alternatives correspond to Level 5 (see Section 6.3)

Figures 49 and 50 summarize the total cost composition for the South Station Expansion (No NSRL) and tunnel alignments, excluding any upstream/downstream improvement costs.

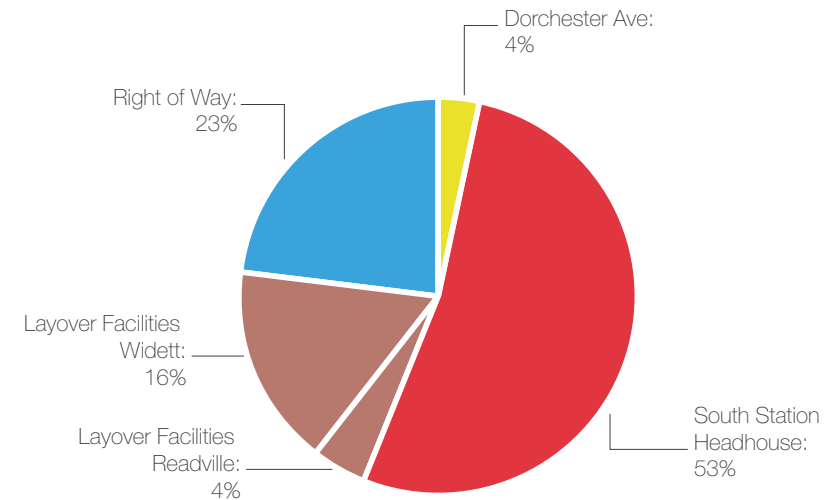


Figure 49: South Station Expansion (No NSRL) Alternative Cost Breakdown

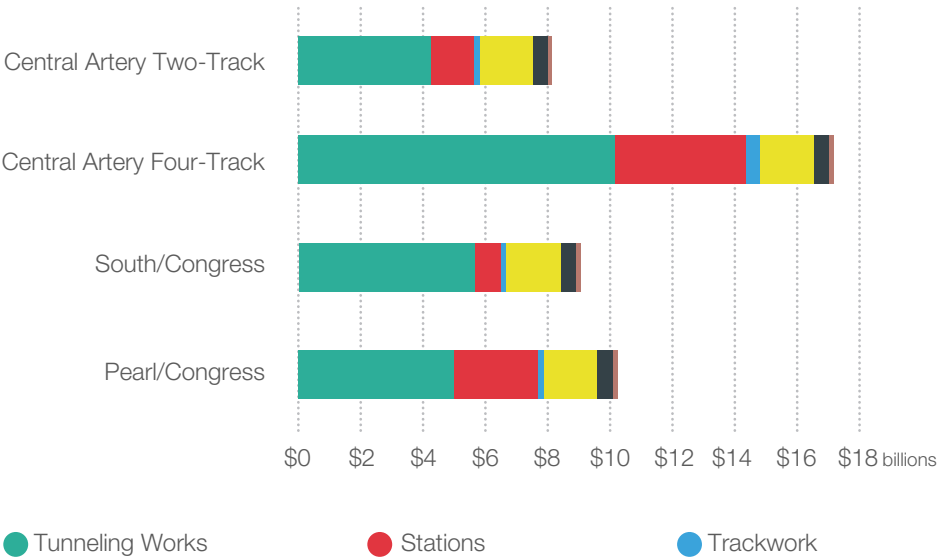
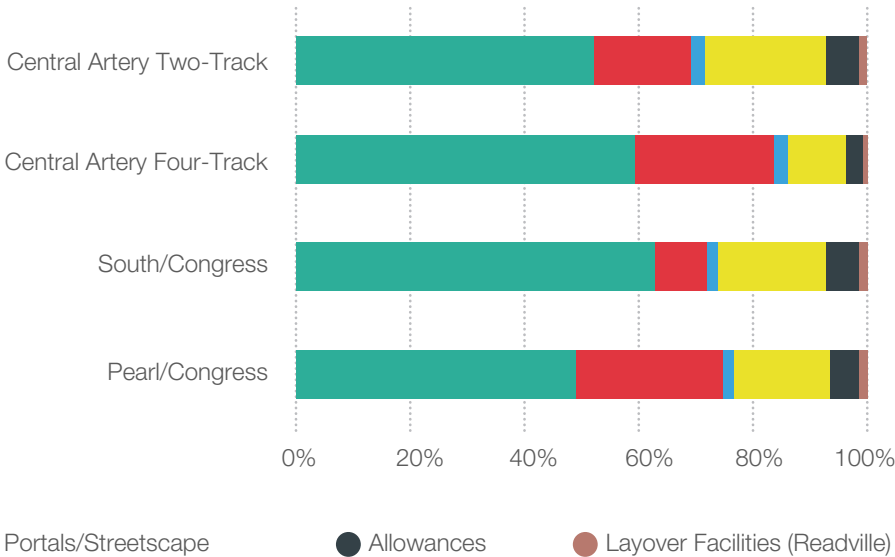


Figure 50: Tunnel Alignments Cost Breakdown (2028 USD)



Among the two-track alignments, the South/Congress alignment has higher tunneling costs than the other two alignments (Central Artery Two-Track and Pearl/Congress). This higher cost is because TBM tunneling costs are driven by the machine's external diameter — a 51-foot-diameter tunnel is exponentially more expensive than two tunnels 29-feet each in diameter or one single tunnel 41-feet in diameter. However, this increase in tunneling costs for the South/Congress alignment is offset by the savings in the mined excavation volumes for the stations, because the 51-foot-diameter TBM bore can accommodate the station platforms as well as the tracks.

The same analysis can be done between the Pearl/Congress and Central Artery Two-Track alignments, where the tunneling costs are similar, but the alignments differ greatly in their station costs. This is because, even though the construction methodology for South Station in the Central Artery Two- and Four-Track alignments requires a cofferdam, the cut-and-cover methodology for building stations remains considerably cheaper than the mined excavation methodology applied to both new underground stations in the Pearl/Congress alignment.

Vehicles – Baseline

The cost estimate for the vehicles includes the cost of the dual-mode locomotives. The South Station Expansion (No NSRL) alternative does not require the purchase of dual-mode locomotives; however, all tunnel alignment options have the same baseline vehicle purchase, as outlined in Table 19. The 'dual-mode swap' in the table refers to a possible credit for the sale of existing diesel locomotives that have not reached the end of their useful life.

Description	Total Costs (\$)
Locomotive – Dual-Mode Swap	264,000,000
Total Rolling Stock Costs	264,000,000
Contingency (5%)	13,200,000
Total Rolling Stock Costs Qtr. 1 2018 USD	277,200,000
Escalation to 2028 MP Construction (41%)	113,818,000
Total Cost Qtr. 1 2028 USD	391,018,000

Table 19: Vehicles – Baseline for Tunnel Alignments

Tier 2 - Improvements

Additional Layover Facilities

The tunnel alignments include an additional layover facility (based on this Feasibility Reassessment's South Station Expansion Widett Circle costs) as part of Tier 2, to accommodate an increased fleet. Right-of-way purchased costs for layover facility are not included. Table 20 summarizes the capital costs of the facility.

Description	Total Costs (\$)
Layover Facilities (Widett Circle)	129,315,400
Total Direct Costs	129,315,400
Indirect Costs (25%)	32,328,900
Subtotal D + I	161,644,300
Contractor's Contingency (10%)	16,164,500
Subtotal	177,808,800
Overhead & Profit (12%)	21,337,100
Total Construction Costs	199,145,900
Design / Engineering (9%)	17,923,200
Total Design Build Price	217,069,100
Soft Costs (15%)	32,560,400
Subtotal Incl. Soft Costs	249,629,500
Project Risk Contingency (15%)	37,444,500
Total Project Costs Qtr. 1 2018 USD	287,074,000
Escalation to 2028 MP Construction (41%)	117,872,300
Total Cost Qtr. 1 2028 USD	404,946,300

Table 20: Additional Layover Facility Costs

Upstream/Downstream Improvements

The upstream/downstream improvement works, ranging from \$590m to \$650m (\$830m to \$915m in 2028), are similar for all alternatives (including the South Station Expansion - No NSRL alternative) and include the following:

- Extra platform capacity (Fitchburg, Franklin, Lowell, Providence/Stoughton, and Worcester Lines)
- Double-tracking improvements (including signaling but excluding electrification for an overhead catenary system) along some or all of the Fitchburg, Needham, Old Colony, Haverhill, and Newburyport/Rockport Lines
- Resignaling of critical points on multiple lines (totaling 30 track miles)
- Turnback crossovers (Franklin and Fairmount Lines)

Table 21 summarizes the total project costs for the upstream/downstream improvements for the South Station Expansion (No NSRL) alternative and the two-track and four-track alignments. Refer to Table E-3 in Appendix E for the detailed estimate.

Description	South Station Expansion (No NSRL) Costs (\$)	Two-Track Tunnel Costs (\$)	Four-Track Tunnel Costs (\$)
Additional platform capacity	17,000,000	12,750,000	17,000,000
Track doubling	95,251,200	120,213,600	120,213,600
Additional Crossovers	3,000,000	4,500,000	4,500,000
Resignaling	150,750,000	150,750,000	150,750,000
Total Direct Costs	266,001,200	288,213,600	292,463,000
Indirect Costs (25%)	66,500,300	72,053,400	73,115,900
Subtotal D + I	332,501,500	360,267,000	365,579,500
Contractor's Contingency (10%)	33,250,200	36,026,700	36,558,000
Subtotal	365,751,700	396,293,700	402,137,500
Overhead & Profit (12%)	43,890,300	47,555,300	48,256,500
Total Construction Costs	409,642,000	443,849,000	450,394,000
Design / Engineering (9%)	36,867,800	39,946,500	40,535,500
Total Design Build Price	446,509,800	483,795,500	490,929,500
Soft Costs (15%)	66,976,500	72,569,400	73,639,500
Subtotal Incl. Soft Costs	513,486,300	556,364,900	564,569,000
Project Risk Contingency (15%)	77,023,000	83,454,800	84,685,400
Total Project Costs Qtr. 1 2018 USD	590,508,300	639,819,700	649,254,400
Escalation to 2028 MP Construction (41%)	242,462,400	262,709,200	266,583,100
Total Cost Qtr. 1 2028 USD	832,971,700	902,528,900	915,837,500

Table 21: Summary of Total Project Costs for Upstream/Downstream Improvements

Vehicles – Increase

The vehicle increase scenario is summarized in Table 22 for the South Station Expansion (No NSRL) alternative, the two-track tunnel (same for all alignments), and the four-track tunnel alignments. In this table, dual-mode locomotive swap shows a credit in order to supersede the monies allocated in Tier 1 for this same item.

Description	South Station Expansion (No NSRL) Costs (\$)	Two-Track Tunnel Costs (\$)	Four-Track Tunnel Costs (\$)
Locomotive – Dual-Mode Swap (from baseline)	-	(72,000,000)	(32,000,000)
Locomotive – Dual-Mode Increment	-	792,000,000	792,000,000
Diesel Locomotive Increment	385,000,000	-	-
Coaches Increment	558,000,000	609,000,000	609,000,000
Battery-Electric Helper Locomotives	-	14,000,000	14,000,000
Subtotal Rolling Stock Costs	943,000,000	1,343,000,000	1,383,000,000
Contingency (5%)	47,150,000	67,150,000	69,150,000
Total Rolling Stock Costs Qtr. 1 2018 USD	990,150,000	1,410,150,000	1,452,150,000
Escalation to 2028 MP Construction (41%)	406,554,400	579,005,900	596,251,000
Total Cost Qtr. 1 2028 USD	1,396,706,400	1,989,155,900	2,048,401,000

Table 22: Vehicle Costs

Table 23 shows the total costs for each alternative, showing subtotals for each of the tiers, in 2028 US dollars.

	No NSRL	Two-Track			Four-Track
Description	South Station Expansion Costs (\$)	Central Artery Costs (\$)	Pearl/Congress Costs (\$)	South/Congress Costs (\$)	Central Artery Costs (\$)
Total Alternative Project Cost	2,465,773,100	8,672,227,100	10,744,078,100	9,536,266,900	17,773,698,000
Vehicles - Baseline	-	391,018,000	391,018,000	391,018,000	391,018,000
Total Tier 1 Costs	2,465,773,100	9,063,245,100	11,135,096,100	9,927,284,900	18,164,716,000
Additional Layover Facilities	-	404,946,300	404,946,300	404,946,300	404,946,300
Total Upstream/ Downstream Improvement Costs	832,971,700	902,528,900	902,528,900	902,528,900	915,837,500
Vehicles – Increase	1,396,704,400	1,989,155,900	1,989,155,900	1,989,155,900	2,048,401,000
Subtotal Tier 2 Costs	2,229,676,100	3,296,631,100	3,296,631,100	3,296,631,100	3,369,184,800
Total Tier 1 + Tier 2 Costs	4,695,449,200	12,359,876,200	14,431,727,200	13,223,916,000	21,533,900,800

Table 23: Summary of Costs by Tier (2028 USD)

6.3 Basis of Estimate

Based on the level of design completed for this Feasibility Reassessment, this estimate is classified as a Level 3 Budget Authorization for the South Station Expansion (No NSRL) alternative and a Level 5 Rough Order of Magnitude estimate for the tunnel alignments. These classifications are per the classification matrix in Table 24, which has been developed in accordance with AACEi's best practices. The table is based on the AACEi Cost Estimate Classification Matrix, which indicates an industry best practice accuracy range and estimate methodology, in relation to the level of design completeness.

Estimate Level	Estimate Description	Design Phase	Level of Completion	Methodology	Accuracy Range
5	Rough Order of Magnitude	Planning Schematic Design	0% to 5%	Parametric Models Capacity Factored Historical Costs	L: -20% to - 50% H: +30% to +100%
4	Concept Feasibility	Planning Schematic Design	1% to 15%	Equipment Factored Parametric Models	L: -15% to - 30% H: +20% to +50%
3	Budget Authorization	Planning Schematic Design Design Documents	10% to 40%	Unit Costs Assembles	L: -10% to - 20% H: +10% to +40%
2	Budget Control Estimate	Preliminary Design Engineering Design Documents Construction Documents	30% to 70%	Detailed Unit Cost Detailed Take-Off	L: -5% to - 15% H: +5% to +30%
1	Bid	Detailed Design Engineering Construction Documents	50% to 100%	Detailed Unit Cost Detailed Take-Off Productivities Subcontractor Quotes	L: -2% to - 5% H: +3% to + 15%

Table 24: AACEi Estimate Classification Matrix

The accuracy ranges with respect to the AACEi Estimate Classification Matrix account for potential fluctuation in the market above standard yearly escalation and changes in the project cost with respect to design development and refinement. Table 25 summarizes the accuracy ranges for the developed estimates.

	Accuracy Range (Low)	Accuracy Range (High)
South Station Expansion - No NSRL (Level 3 Estimate)	-20%	+40%
Tunnel Alignments (Level 5 Estimate)	-30%	+50%
Upstream/Downstream Improvements (Level 5 Estimate)	-50%	+100%

Table 25: Estimate Accuracy Ranges

6.4 Assumptions and Exclusions

The project cost estimate was performed with the following assumptions:

1. For the South Station Expansion (No NSRL) alternative, an allowance of \$400m (\$565 in 2028) has been made to account for all real estate acquisition costs and required relocation expenses related to right-of-way purchases.
2. For the tunnel alignments, it has been assumed that the real estate acquisitions for all tunneling, station, and portal works will be covered by the net sales of proceeds, and therefore no incremental cost has been assumed in the estimate.
3. For the tunnel alignments, it has been assumed that no service interruption or constrained work hours will affect the schedule of construction, and therefore no premium has been included to account for this.
4. It has been assumed that there are no right-of-way constraints for layover yards and staging areas within the vicinity of the project, and therefore no additional costs have been included to account for this.
5. No allowances have been made in the direct costs for hazardous material removal and disposal.
6. It has been assumed that there will be no constraints in disposal sites to allow for the disposal of the large quantity of excavated material (>2 million cubic yards).



$l = 20 \times \text{tunnel diameter}$

$w = 2 \times \text{diameter} \times \# \text{ of tunnels} \times 1.25$

$d(1) = 2.5 \times \text{diameter}$ if diameter = 29ft

$d(2) = 2 \times \text{diameter}$ if diameter = 41.5ft

$d(3) = 1.6 \times \text{diameter}$ if diameter = 51.2ft

Figure 51: TBM Launch Pit Schematic

7. TBM launch pit quantities have been calculated based on the schematic in Figure 51.
8. Utility relocation allowances have been made based on benchmarks from other projects and broken down by utility relocations at stations and utility relocations for tunnel works.
9. It has been assumed that the trackwork inside the tunnels will be direct fixation, i.e., concrete embedded.
10. A 25% productivity reduction factor has been included in the Back-Bay portal civil works.

6.5 Schedule

Overview of Schedule

A high-level procurement and construction schedule was developed for the South Station Expansion (No NSRL) and tunnel alignments, based on production rate benchmarks for similar projects. Different schedules have been produced for each alternative.

Figures 52 and 53 show the high-level schedule for each alternative.

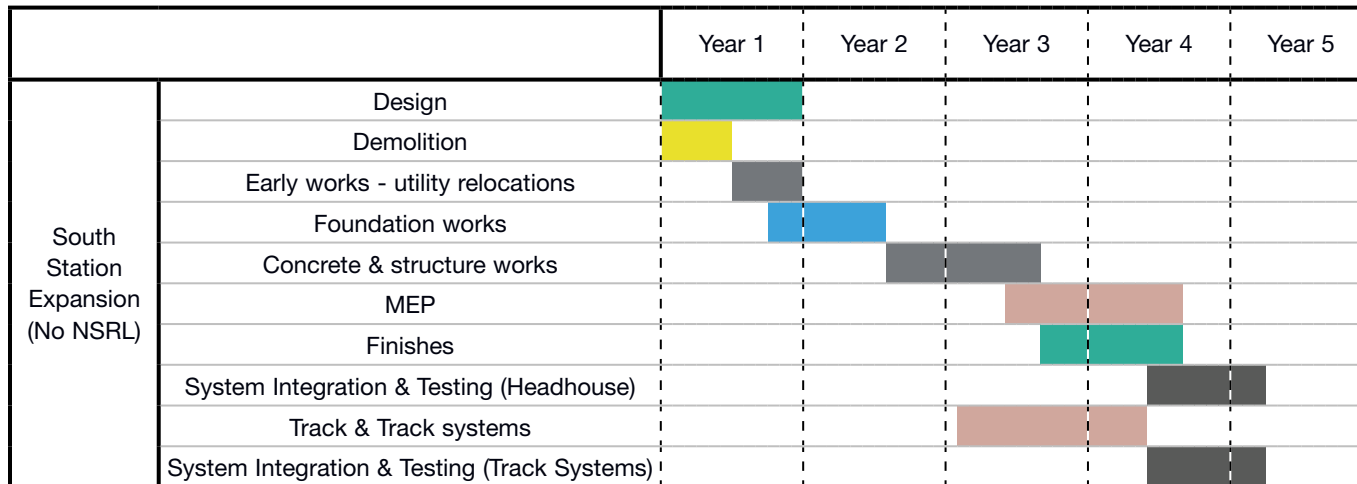


Figure 52: Schedule Summary for the South Station Expansion (No NSRL) Alternative

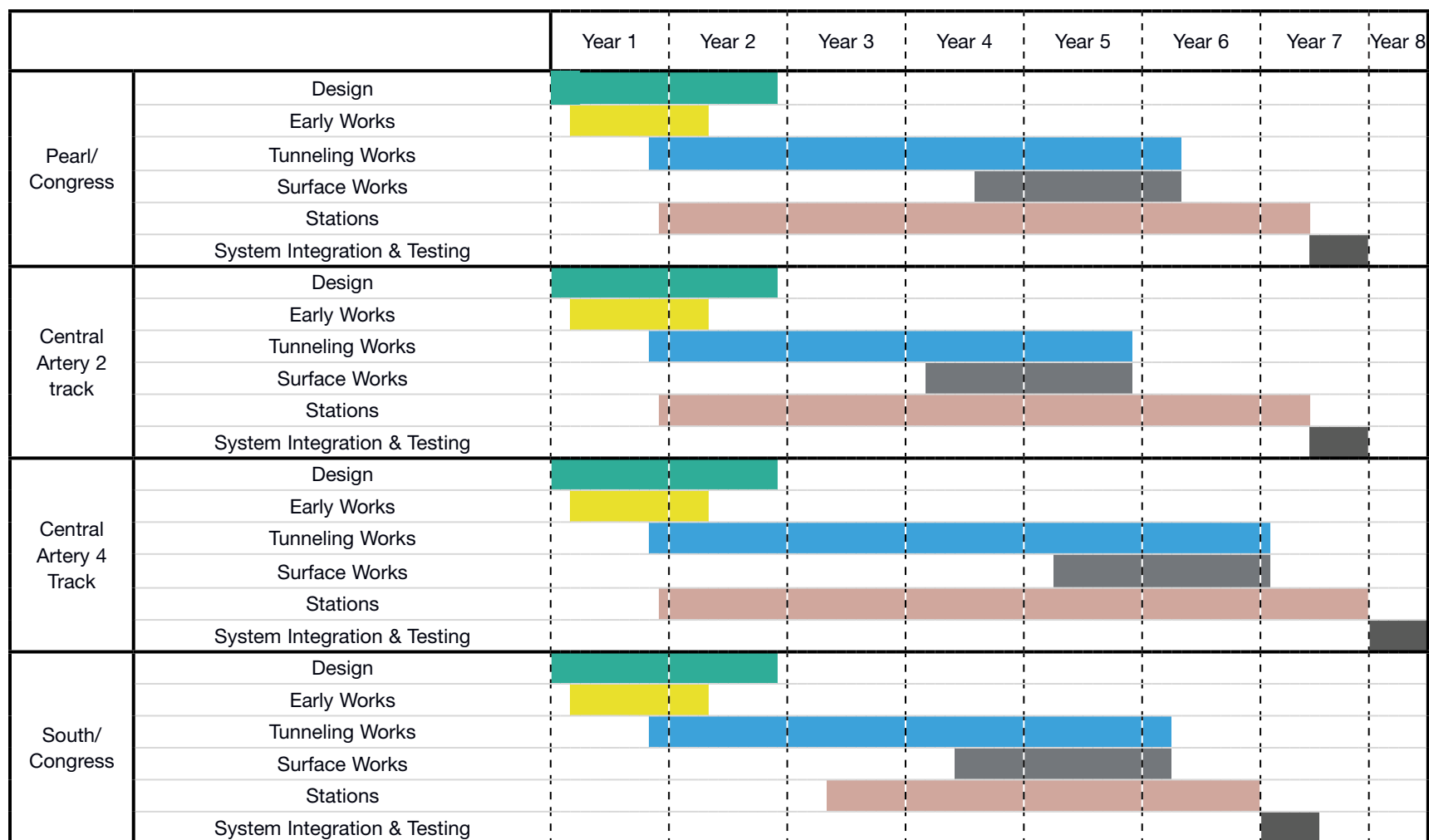


Figure 53: Schedule Summary for All NSRL Tunnel Alignments

Basis of Schedule

The schedule is a Class 5 schedule per AACEi Recommended Practice document 27R-03 (see Table 26). Schedule accuracy is dependent on the work sequencing and chosen construction means and methods. The schedule presented represents a single alternative for sequencing. Alternative sequencing options may produce a more optimized schedule.

Schedule Class	Primary Characteristic	Secondary Characteristic	
	Degree of Project Definition (Expressed as percent of complete definition)*	End Usage	Scheduling Methods Used
Class 5	0% to 2%	Concept screening	Top-down planning using high-level milestones and key project events.
Class 4	1% to 15%	Feasibility study	Top-down planning using high-level milestones and key project events. Semi-detailed.
Class 3	10% to 40%	Budget, authorization, or control	“Package” top-down planning using key events. Semi-detailed.
Class 2	30% to 70%	Control or bid/tender	Bottom-up planning. Detailed.
Class 1	70% to 100%	Bid/tender	Bottom-up planning. Detailed.

Table 26: AACEi Schedule Classification Matrix

*RP 18R-97 provides the range in percentages for each class.

7. Benefits Analysis



Photo Source: Wikimedia Commons, User Pi.1415926535

7. Benefits Analysis

The NSRL project has been expected to generate benefits to rail passengers, transportation system users and the broader public. The Problem Statement in Chapter 2 outlined the current system deficiencies, which the project seeks to resolve. This chapter identifies the anticipated performance of the project, including its social and economic impacts. These benefits range across six categories:

- **Mobility Impacts** – Includes increased ridership, travel time savings, and mode shift from automobile to transit
- **Employment Access** – How the NSRL project affects access to employment compared to the No Build scenario.
- **Operational Efficiencies** – The impact of rail unification on the overall state of good repair of the rail system, including operational efficiencies
- **Economic Impacts** – Potential development opportunities directly attributable to the project and effects from construction and operation expenditures
- **Environmental Justice Impacts** – How the NSRL project affects fair access to housing and economic opportunities, particularly for environmental justice (EJ) communities
- **Air Quality Impacts** – Determine environmental and public health impacts to the extent possible

While there may be other benefits that accrue from an investment like the NSRL (such as increased development or tourism potential across the MBTA

Commuter Rail system), MassDOT's analysis focused on the listed benefits as they can be significant and can be measured with available data. Benefits that rely on changes to local land use controls, over which MassDOT has no jurisdiction, were deemed to be speculative and not necessary for an assessment of the project's overall benefit.

A standardized methodological framework was used to assess quantifiable benefits: the No Build and the build alternatives are compared to measure the incremental value that the NSRL project creates in the region. All dollar amounts are in 2018 USD.

Most of the project's benefits derive from its effect on the total transportation system, which in turn impacts the activities of area residents. The CTPS ridership forecasts are the basis for the benefits analysis, as changes in MBTA Commuter Rail ridership impact other parts of the transit system as well as the highway system. These impacts can then affect emissions and equity. Other project benefits are closely related to the expenditure of resources necessary to deliver the project and operate the system, and those expenditures ripple through the regional economy.

7.1 Methodology for Quantifiable Benefits

Quantifiable benefits were measured by comparing the No Build against the build alternatives.

Definition of the No Build and Build Alternatives

No Build

The No Build alternative corresponds to the physical and economic environment absent the NSRL facility and its proposed operations, and assesses the consequences of the project not taking place. This alternative represents the reference point against which the incremental benefits and costs of the NSRL build alternatives will be measured.

The No Build alternative does not assume the status quo or today's conditions – it includes all the projects and programs identified in the fiscally constrained Regional Transportation Plan (RTP) adopted by the Boston Region MPO, including various MBTA Commuter Rail improvements as well as rapid transit, bus and highway projects. The South Coast Rail alignment via Middleborough is also included, but the South Station Expansion project is not included in the RTP and hence is not included in the No Build alternative. The No Build alternative (as well as all of the build alternatives) assumes the region's forecast employment and population growth as developed by MAPC (the Boston region's planning agency) per the currently endorsed MetroFutures regional land use plan.

The Build Alternatives

The benefits analysis considers three build alternatives. Chapter 4 defines the service characteristics of the alternatives, and their physical characteristics are detailed in Chapter 5 and costed in Chapter 6. These three alternatives and their associated service assumptions are as follows:

- Surface, or South Station Expansion & All-Day Peak Service (No NSRL) – This alternative assumes that South Station is expanded to 20 tracks (a 50% increase in capacity) as per the proposals of the South Station Expansion project, three to four additional trains operate in the peak hour, and peak-period service levels continue throughout the day. At North Station, an additional two trains are added in the peak hour (accommodated by the North Station Bridge rebuild project) and the peak-period service levels operate throughout the day.
- Two-Track, or NSRL All-Day Peak Service (Two-Track). Physical alignments are Central Artery, South/Congress or Pearl/Congress) – In this alternative, a two-track tunnel is assumed and peak period service operates throughout the day (essentially at the same service frequencies as the South Station Expansion alternative, with slightly more service to the north side suburbs). In Chapter 4, a service variation for the Two-Track tunnel reduced service midday. That variation is not considered in the benefits analysis to allow consistency among all the build alternatives. For

the purposes of the benefits analysis, the three Two-Track alignments are considered as having equal ridership and economic benefits; however, a separate analysis of changes in each alignment's Downtown catchment area is provided.

- Four-Track, or NSRL All-Day Peak Service (Four-Track) – In this alternative, in addition to the service operated by the NSRL All-Day Peak Service (Two-Track) alternative, the Fairmount Line is routed through a separate two-track tunnel, creating a four-track system.

7.2 Mobility Impacts

Transit improvements can generate mobility benefits to both users and non-users of the transit network. Some of these benefits were quantified through CTPS' travel demand model, based on 2040 population and employment forecasts (model assumptions, framework, and outputs are described in detail in Appendix C). This model aims to predict traveler behavior using different transportation infrastructure networks and pricing structures. Other changes to traveler behavior, such as comfort, legibility and reliability, are subtler and more difficult to quantify.

An important consideration in the benefits discussion concerns the travel model's reliance on existing behavior. This behavior is based, in turn, on existing infrastructure. As a result, the model cannot anticipate regional travel shifts (for example, more people moving to the municipalities on the north side of the MBTA Commuter Rail system while keeping jobs in Back Bay and the Boston Financial District) or even the willingness of companies to locate along north side commuter rail lines as a result of the improved access into Downtown Boston and the municipalities on the south side of the rail network.

Figure 54 illustrates the quantifiable benefits considered in this analysis and their CTPS source data. All build alternatives are expected to generate similar benefits, but the magnitude of the benefits vary with each alternative.

Improvements in service frequency (assumed in all build alternatives) and in connectivity through the construction of the NSRL tunnel (both the Two-Track and Four-Track build alternatives) will result in:

- **Travel time savings for MBTA Commuter Rail users** as wait times would be reduced due to more frequent service.
- **Reduced crowding on parallel MBTA rapid transit lines** as commuter rail improvements serve to relieve crowding on parallel or connecting rapid transit lines.

- **Travel time savings for travellers who shifted from automobile to MBTA Commuter Rail** as improvements in commuter rail service are expected to make this mode choice more attractive and induce automobile drivers to shift modes.
- **Mode shift from automobile to MBTA Commuter Rail** which in turn will generate benefits to roadway users and the broader public:
 - **Reduction in vehicle miles traveled (VMT)** as there are fewer vehicles on the road
 - **Reduction in vehicle emissions** as there will

be fewer vehicle miles travelled

- **Potential savings in travel time from auto drivers** as there is a reduction in the number of vehicles on the roadway system (opening up more capacity)

Safety benefits from accident reduction were not considered because there is no consistent paradigm to measure the consequences of having fewer vehicles on the roadway system. As an example, fewer vehicles on the roadway can lead drivers to drive faster and result in higher-severity accidents.

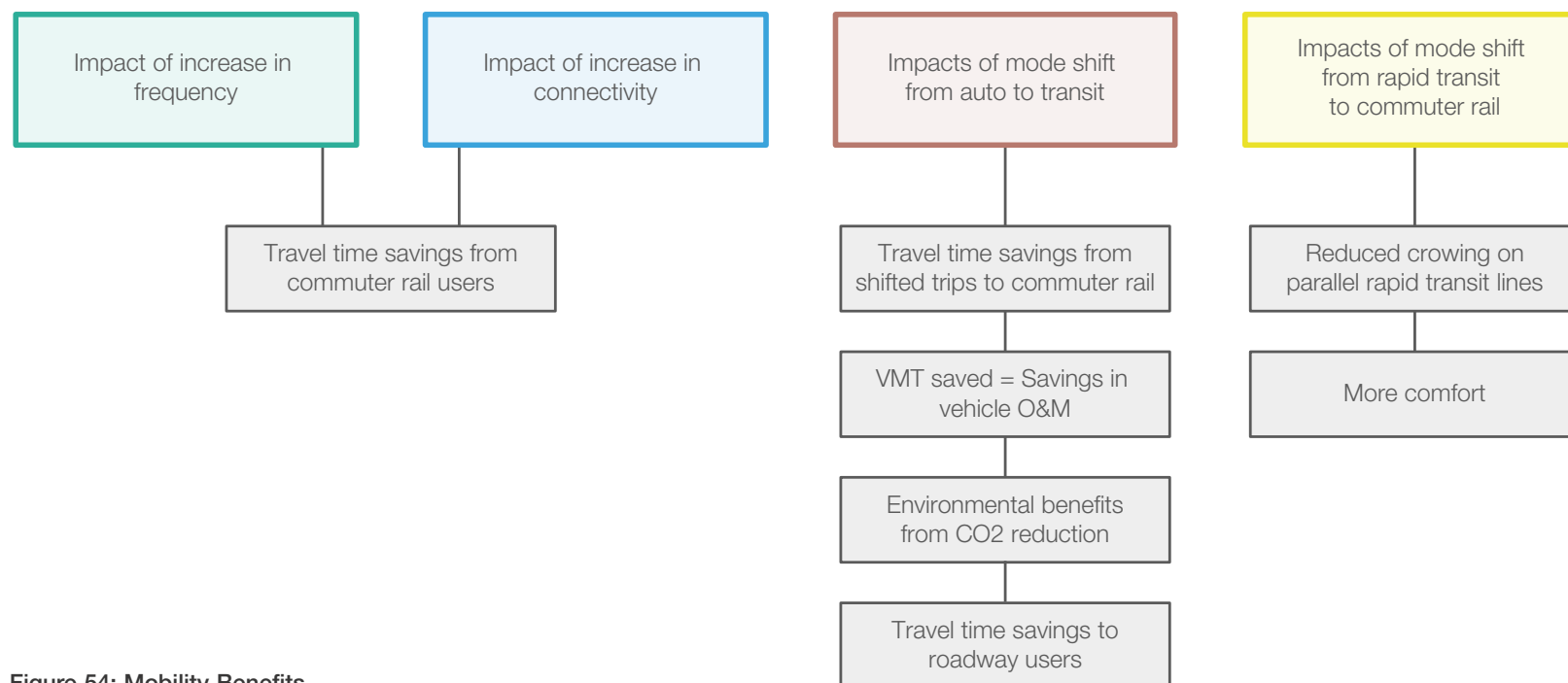


Figure 54: Mobility Benefits

Ridership and Mode Shift

The NSRL project, as noted in Chapter 4, creates more transportation capacity into Downtown Boston – anywhere from about 44,000 No Build peak-hour seats to almost 60,000 peak-hour seats with the NSRL All-Day Peak Service (Two-Track) alternative.

The results from the CTPS model forecast daily 2040 No Build commuter rail ridership of about 150,000 trips. More than 60% of passengers begin their trips on routes currently serving South Station, with the balance – less than 40% – using trains destined for North Station. This is consistent with existing travel patterns. As service is improved and the connectivity between North and South Stations via the NSRL tunnel is made viable through the Two-Track and Four-Track build alternatives, ridership from the north side of the rail system increases more than from the south side, in relative terms.

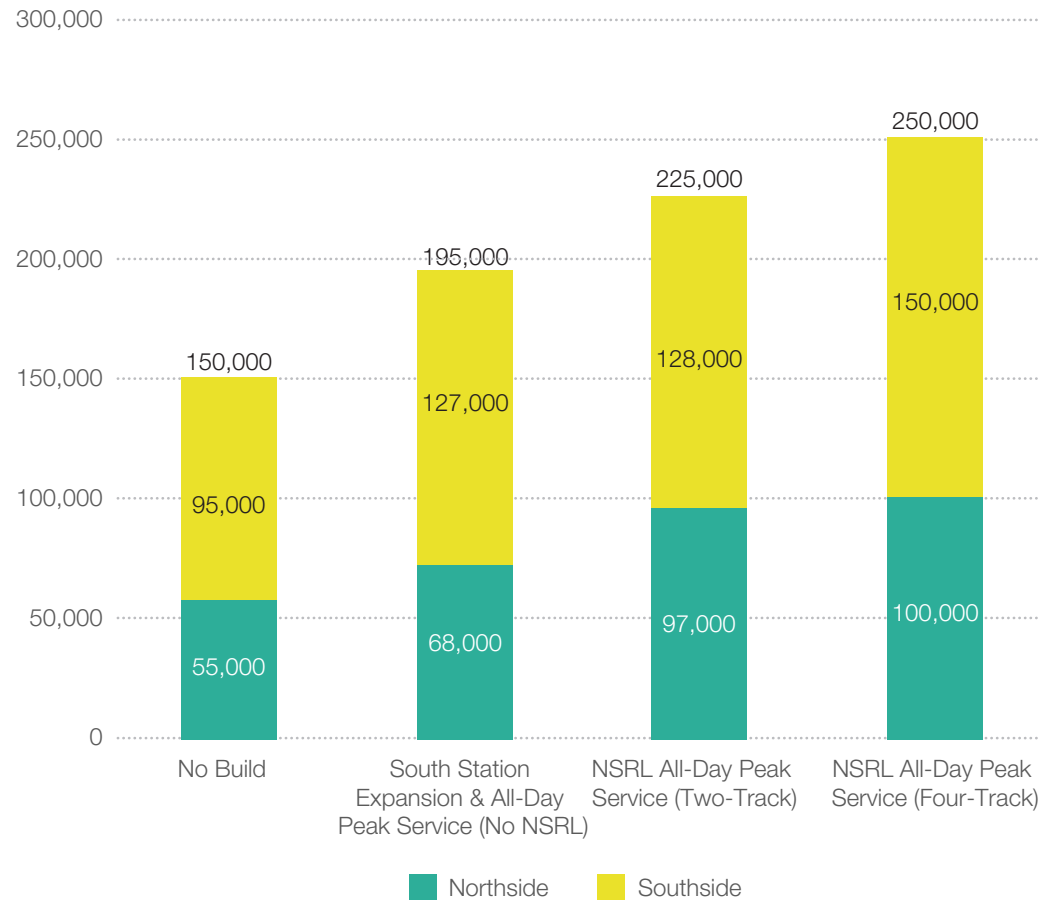


Figure 55. 2040 Commuter Rail Ridership by Alternative (Daily one-way trips)

Source: Ridership data from CTPS model. Note: Totals rounded.

As summarized in Chapter 4, ridership increases in each of the build alternatives. However, the benefits of these increases are different depending on its specific alignment.

In the **South Station Expansion & All-Day Peak Service (No NSRL)** alternative (the build alternative lacking the NSRL Tunnel), the frequency and service increases (enabled by the higher capacity at South Station) and the increase in service to North Station increase ridership as illustrated in Table 27.

For the south side of the commuter rail network, trips outside Route 128 dominate the travel market, reflecting the large rider base on the Providence and Franklin Lines. As service levels increase, however, off-peak trips are equally split between those from within and outside Route 128. The north side of the network generates more trips from within Route 128 than from outside.

In the **NSRL All-Day Peak Service (Two-Track)** alternative, ridership from the south side does not increase beyond that forecast in the South Station Expansion & All-Day Peak Service (No NSRL); however, ridership from the north side increases.

Compared to the No Build scenario, the north side of the commuter rail system experiences a large ridership increase – more than 75%. At least two-thirds of this increase is solely related to the improved tunnel connection into Downtown Boston (a total of almost 30,000 trips). On the north side of the rail system, the split between origins within

Origin Area	Daily Ridership Increase	Percentage Increase	All Trips from Inside Route 128	All Trips from Outside Route 128
South Side	32,000	34%	25%	75%
North Side	13,000	24%	55%	45%

Table 27: South Station Expansion & All-Day Peak Service (No NSRL) Ridership Origins

Source: Estimates based on CTPS travel demand model

Origin Area	Daily Ridership Increase	Percentage Increase	All Trips from Inside Route 128	All Trips from Outside Route 128
South Side	33,000	34%	40%	60%
North Side	42,000	75%	55%	45%

Table 28: NSRL All-Day Peak Service (Two-Track) Ridership Origins

Source: Estimates based on CTPS travel demand model

and outside Route 128 remains consistent with the South Station Expansion & All-Day Peak Service (No NSRL) alternative. From the south side, the provision of the tunnel increases ridership within Route 128 in the off-peak to about 60%, which in turn reduces the daily split to 60%/40%, favoring trips beyond Route 128.

In the **NSRL All-Day Peak Service (Four-Track)** alternative, ridership trends mimic the NSRL All-Day Peak Service (Two-Track) alternative.

A comparison of the South Station Expansion & All-Day Peak Service (No NSRL) alternative and the Two-Track and Four-Track build alternatives shows an increase in ridership from the north side. In the tunnel build alternatives, 40-45% of passengers are originating from the north side, even though ridership on the south side lines increases. This roughly 5% shift towards north side originating traffic compares to the existing system ridership split of about 60-65% from the south and about 35-40% from the north.

Origin Area	Daily Ridership Increase	Percentage Increase	All Trips from Inside Route 128	All Trips from Outside Route 128
South Side	55,000	58%	45%	55%
North Side	45,000	82%	55%	45%

Table 29: NSRL All-Day Peak Service (Four-Track) Ridership Origins

Source: Estimates based on CTPS travel demand model

Gateway Cities

The Commonwealth of Massachusetts identifies Gateway Cities as midsize urban centers anchoring regional economies. During their industrial heyday, these economic and industrial hubs offered residents good jobs and a “gateway” to the American Dream. However, during the last several decades, manufacturing jobs slowly disappeared. While Greater Boston benefited from “new economy” jobs, Gateway Cities have been slow to draw similar interest or investment. As part of a renewed focus on these areas, studies and proposals suggest that land use and infrastructure changes (such as the NSRL) may enable Gateway Cities to again serve as economic catalysts. Small entrepreneurial businesses that fuel job creation in today’s economy may be attracted to walkable and innovative urban environments, like the ex-industrial, relatively dense Gateway Cities. MassINC, a regional think tank, reports that “Gateway City TOD will produce a heavy stream of new riders; the commuter rail system has capacity to carry

these additional passengers with limited marginal cost”. The MassINC report also notes that improved transportation is a key part of its strategic vision for a “Transformational Gateway City TOD”.²²

Within the MBTA Commuter Rail service area are 25 Gateway Cities, and there are commuter rail stations in 16 of these cities. In the build alternatives, service is substantially increased to 11 of these cities (Gateway Cities on the Old Colony Lines and the South Coast Rail extension have limited service increases due to upstream capacity constraints).

The average ridership increase related to the Two-Track and Four-Track build alternatives is about 35% on the south side of the rail system and about 75% on the north side of the rail system; however, Gateway Cities’ ridership changes are more pronounced.

Table 30 identifies the ridership increase in north side and south side Gateway Cities directly served by the MBTA Commuter Rail.

The provision of additional service and the tunnel alternatives have marginal benefits for the southern Gateway Cities (Worcester and Attleboro); however, Gateway Cities north of Boston experience significant ridership gains, from an increase in service frequency and substantially with the provision for direct service to Downtown Boston and Back Bay. The higher service frequencies almost double ridership from north side Gateway Cities, and direct service to Downtown Boston almost triples ridership, compared to the No Build alternative.

Transit Access to Employment

As described in Section 5, each Two-Track alignment (Central Artery, South/Congress, and Pearl/Congress) has its own combination of two station locations (the Four-Track alignment – Central Artery - has three stations). These combinations provide access to slightly different areas of Downtown Boston, based on the locations of their indicative entrances and exits, or “headhouses”.

A number of analyses were conducted to determine the accessibility benefits of each alignment and focused on the accessibility changes related to the locations of the proposed stations relative to the existing South Station and North Station. A key accessibility benefit is the number of jobs accessible within a ten-minute walk from the center of each station location. Table 31 summarizes the job catchment for each alternative and its station combination using 2040 predictions for job growth

	No Build	South Station Expansion & All-Day Peak Service (No NSRL)	Change (%)	NSRL All-Day Peak Service (Two-Track)	Change %
North Side Gateway Cities	8,136	15,598	92%	23,493	189%
South Side Gateway Cities	4,459	5,115	15%	5,031	13%

Table 30: Gateway Cities Commuter Rail Ridership Increases, by Alternative

Source: Project Analysis of CTPS Data, both directions of travel.

from CTPS, to align with the build year for the NSRL project.

Several steps were completed to draw the boundaries circumscribing a ten-minute walk from the center of each station and to then calculate the number of 2040 jobs that fall within these boundaries, as follows:

- For underground stations only, it was first assumed that passengers have an in-station travel time of three minutes before exiting the station from one of the headhouses.
- It was then assumed that passengers walk at a speed of about three miles per hour (equivalent to about 4.5ft per second) for ten minutes (for the existing condition and No Build surface stations) and the remaining seven minutes (for underground stations).
- The above yields a walkshed of about 1,900ft (approximately 0.36 miles) per seven minutes.
- The number of jobs within each resultant walkshed were then calculated by identifying which standard census areas (traffic analysis zones, or TAZs) fell within those walksheds. The relevant CTPS 2040 jobs data were queried on an 'all-or-nothing' rule. If the center of the TAZ touches the headhouse's walkshed, it was counted. An additional 125ft in either direction was allowed for some edge cases, to determine whether a TAZ employment is considered.

Alignment Name	Stations	Total Employment (2040)
No Build	Existing North and South Station headhouses/exits	155,311
Surface (No NSRL)	Existing North and South Station headhouses/exits	155,311
Central Artery Two-Track	New South Station and North Station headhouses/exits	158,820
Central Artery Four-Track	New South Station, Central Station and North Station headhouses/exits	172,656
South/Congress	New South Station and North Station headhouses/exits	163,935
Pearl/Congress	New South Station and North Station headhouses/exits	158,826

Table 31: 2040 Employment Within 1,900ft (~7 Min Walk) from Station Headhouses (Existing and Proposed), by Alignment

- The walksheds for each station headhouse were merged and a total walkshed for each alignment was created. Total job counts for these walksheds were calculated, subtracting any within overlapping station walksheds.

The alignments offer ten-minute walk access to similar numbers of 2040 jobs (with a range of plus/minus 5%). The Central Artery Four-Track alignment walkshed yields the greatest number of jobs, which is unsurprising as its third station provides access to a greater area of Downtown Boston. Out of the alternatives with only two stations, the South/

Congress walkshed encompasses a slightly higher number of jobs, likely because of its combination of good access from both the State-Haymarket location and the South Street entrance to South Station. The Central Artery Two-Track and Four-Track alternatives provide good access to the Seaport area (where employment is expected to grow significantly by 2040), but less access to other parts of the Financial District. Figures 56 through 60 show the walksheds from stations for each alignment, as well as the walkshed for the existing North and South Stations.

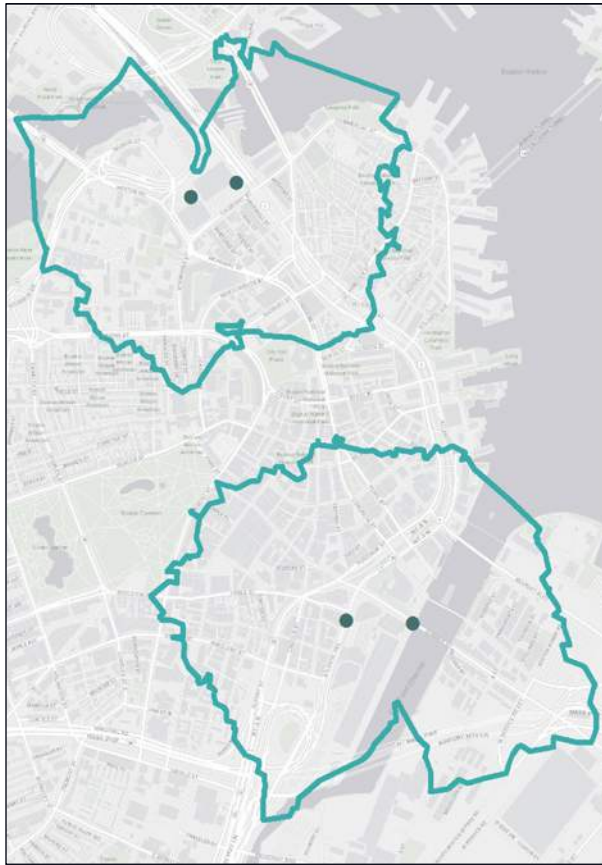


Figure 56: No Build and Surface (No NSRL) Walkshed (Existing Conditions)



Figure 57: Central Artery Two-Track Walkshed

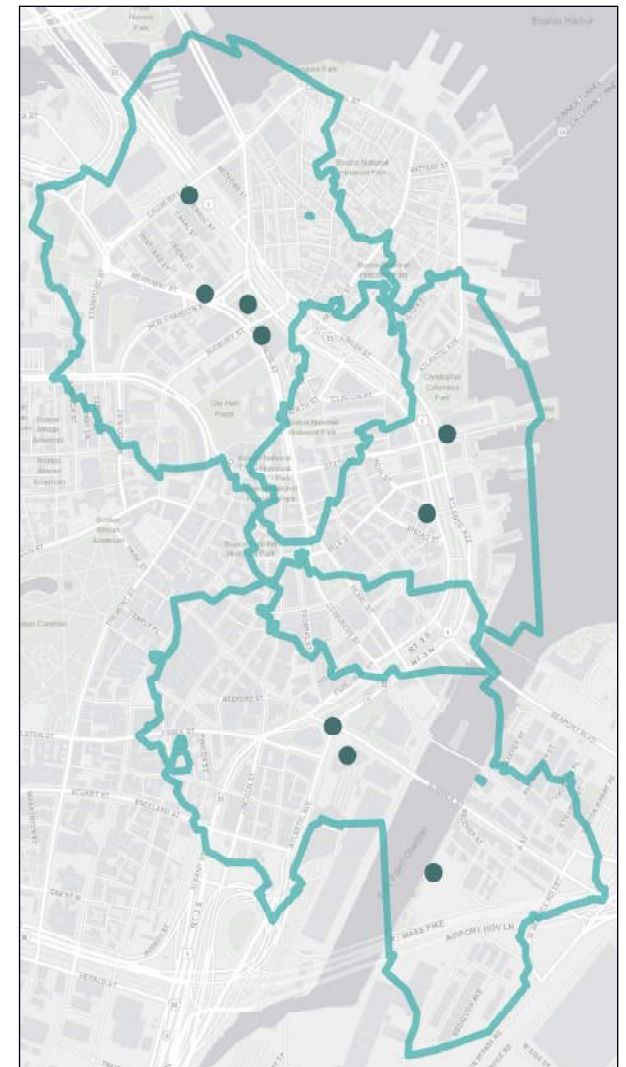


Figure 58: Central Artery Four-Track Walkshed

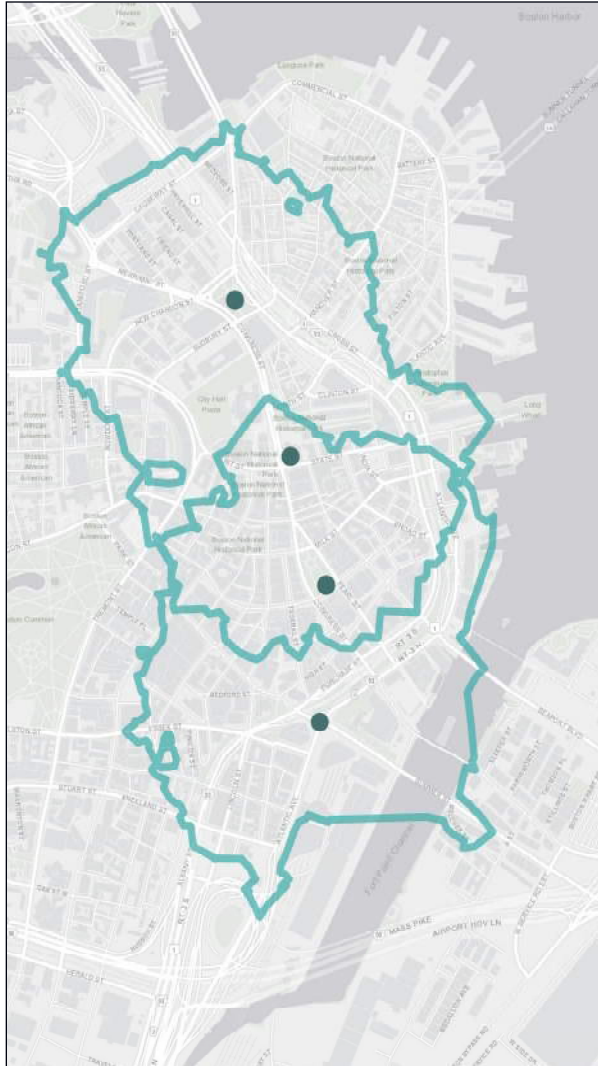


Figure 59: Pearl/Congress Walkshed

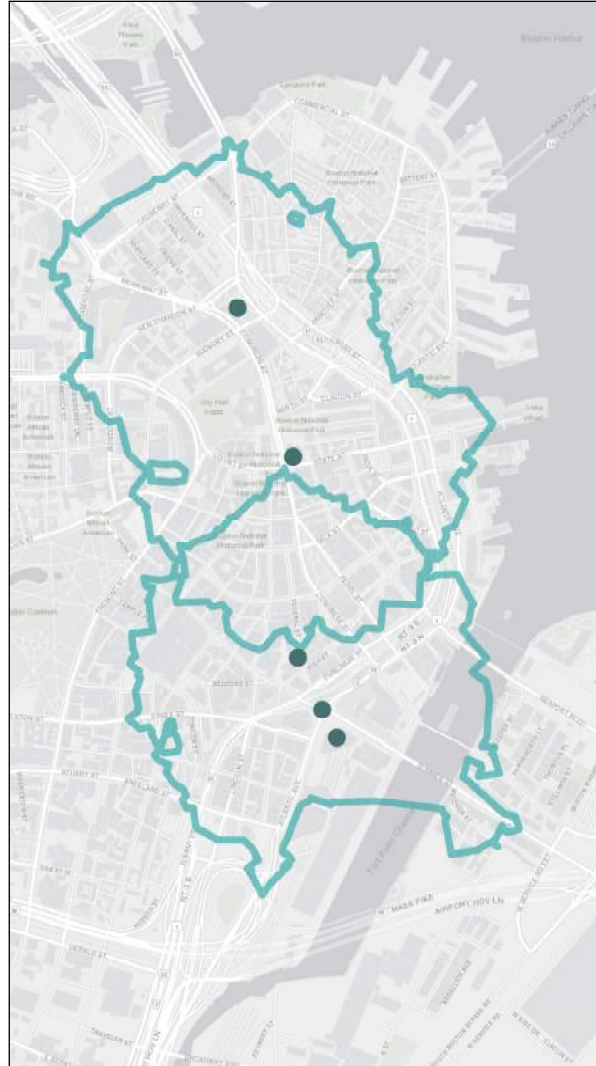


Figure 60: South/Congress Walkshed

MBTA Commuter Rail Travel Time Savings

MBTA Commuter Rail travel time savings come from two sources:

- **Existing users** who will benefit from service improvements
- **New users** who are anticipated to shift automobile to commuter rail because of a more convenient and faster rail service

Existing Rail Users

Benefits to existing MBTA Commuter Rail users arise primarily from an increase in the frequency of trains and connectivity. The CTPS travel demand model estimates that on average, existing riders save three minutes per trip in the South Station Expansion & All-Day Peak Service (No NSRL) alternative and 6.5 minutes per trip in the NSRL All-Day Peak Service (both Two-Track and Four-Track), compared to the No Build alternative. The travel time savings double in the Two-Track and Four-Track alternatives, due to the connectivity and walkability improvements of linking the north side and south side commuter rail systems. Though the savings may seem modest at the individual level, in the aggregate they represent millions of hours saved per year; and for certain trips, the individual time savings can be substantial (details are in Table 33). Savings total approximately two million hours for the South Station Expansion & All-Day Peak Service (No NSRL) alternative and more than four million hours for both the NSRL All-Day Peak Service (both

Two-Track and Four-Track) alternatives, as shown in Table 32.

The benefits from improved MBTA Commuter Rail service were estimated by using the No Build 2040 ridership numbers (150,000 daily riders) as a baseline and allocating the average travel time savings per trip from each build alternative. A factor of 271 (per CTPS guidance) was used to convert daily values into annual numbers.

Sample Trips

To better understand the more specific travel time impacts of the NSRL, a number of sample trips were identified. These sample trips were a mix between those that can be completed by MBTA Commuter Rail today, and those that currently require multiple transfers. As Table 33 shows, the trips that benefit the most from the NSRL tunnel being constructed see time savings ranging from 20-40%, (depending on the build alternative), while others of this same type see a more modest improvement in travel times (less than 10%).

	South Station Expansion & All-Day Peak Service (No NSRL)	NSRL All-Day Peak Service (both Two-Track and Four-Track)
Daily (min)/trip saved	3.0	6.5
Total daily hours saved	7,500	16,250
Total Annual hours (x 271)	2,032,500	4,403,750

Table 32: 2040 Existing Commuter Rail Users - Average Travel Time Savings per Alternative Compared to No Build

Source: Estimates based on CTPS data

From	To	Existing		No Build		NSRL All-Day Peak Service (Two-Track)		NSRL All-Day Peak Service (Four-Track)	
		Path/Routes	Min	Path/Routes	Min	Path/Routes	Min	Path/Routes	Min
Waltham Station	Back Bay Station	Fitchburg -> Red -> Orange	56	Fitchburg -> Red -> Orange	54	Fitchburg	40	Fitchburg	42
Lynn Station	Seaport (Seaport Blvd / Boston Wharf Rd)	Rockport/ Newburyport -> SL3 -> Walk from WTC	50	Rockport/ Newburyport -> SL3 -> Walk from WTC	50	Rockport/ Newburyport -> Walk	47	Rockport/ Newburyport -> Walk	48
Lowell Station	Ruggles Station	Lowell -> Orange	75	Lowell -> Orange	74	Lowell/ Providence	66	Lowell/ Providence	66
W. Roxbury Station	Brandeis-Roberts Station	Needham -> Red -> Fitchburg	88	Needham -> Red -> Fitchburg	87	Fitchburg/ Needham	68		
Route 128 Station	Winchester Station	Providence -> Red -> Orange -> Lowell	88	Providence -> Red -> Orange -> Lowell	86	Providence/ Lowell	48	Providence/ Lowell	44

Table 33: Sample Trips on CR Network – Existing and No Build/Build Alternatives

Note: Travel time includes initial wait time, transit run time, transfer walk time, and transfer wait time

New Rail Users

The CTPS model estimates both the number of trips that would shift from automobile to MBTA Commuter Rail and the travel time savings for these new commuter rail users. Table 34 shows that the South Station Expansion & All-Day Peak Service (No NSRL) alternative is expected to save travelers who shifted from auto to commuter rail 45 daily hours compared to the No Build, and the NSRL All-Day Peak Service (both Two-Track and Four-Track) alternatives are expected to generate twice as much travel time savings than the South Station Expansion & All-Day Peak Service (No NSRL) alternative. On an annual basis, the South Station Expansion & All-Day Peak Service (No NSRL) alternative would save about 12,200 hours, the NSRL All-Day Peak Service (Two-Track) alternative 25,600 hours and NSRL All-Day Peak Service (Four-Track) alternative 28,500 hours.

Roadway Impacts

Roadway Benefits: Vehicle Hours Traveled

Roadway benefits are measured as travel time savings (quantified as vehicle hours traveled, or VHT). These benefits accrue to those travelers who continue to commute by automobile in 2040 for all build alternatives, as compared to the No Build. This is due to less congestion on the highway network as some auto travelers shift to commuter rail. Annual travel time savings for auto drivers could attain three million hours for the South Station Expansion &

		South Station Expansion & All-Day Peak Service (No NSRL)	NSRL All-Day Peak Service (Two-Track)	NSRL All-Day Peak Service (Four-Track)
A)	Daily Hours Saved	35	77	85
B)	Daily Hours Saved Adjusted for Vehicle Occupancy (A x 1.2)	45	95	105
C)	Total Annual Hours (B x 271)	12,200	25,600	28,500

Table 34. 2040 New Commuter Rail Users – Average Travel Time Savings per Alternative Compared to No Build

Source: Estimates based on CTPS data. Numbers were rounded.

		South Station Expansion & All-Day Peak Service (No NSRL))	NSRL All-Day Peak Service (Two-Track)	NSRL All-Day Peak Service (Four-Track)
A)	Potential Daily VHT Saved (adjusted for Vehicle Occupancy) in Hours	11,285	26,560	29,510
B)	Potential Annual VHT Saved, in Hours (A x 271)	3,055,000	7,197,490	7,997,210

Table 35. 2040 Auto Users – Potential Annual VHT Savings per Alternative Compared to No Build

Source: Estimates based on CTPS data. Numbers were rounded.

All-Day Peak Service (No NSRL) alternative, about seven million hours for the NSRL All-Day Peak Service (Two-Track) alternative and almost eight million hours for the NSRL All-Day Peak Service (Four-Track) alternative.

Roadway Benefits: Vehicle Miles Traveled

For those commuters who shifted from automobile to MBTA Commuter Rail, VMT declines for all project alternatives. This is attributed to the fact that these travelers are driving less and as a result will experience savings in their vehicle operating and maintenance costs.

Highway Capacity

There is substantial research indicating that, absent market pricing policies, increases in capacity do not result in less highway congestion. A study from the National Center for Sustainable Transportation at UC Davis notes that adding highway “capacity decreases travel time, in effect lowering the ‘price’ of driving; and when prices go down, the quantity of driving goes up. Induced travel counteracts the effectiveness of capacity expansion as a strategy for alleviating traffic congestion. It also offsets (in part or in whole) reductions in GHG emissions that would result from reduced congestion.”²³ In the context of the NSRL project, the reductions in VMT may not occur, however an increase in regional transportation capacity is created.

		South Station Expansion & All- Day Peak Service (No NSRL)	NSRL All-Day Peak Service (Two-Track)	NSRL All-Day Peak Service (Four Track)
A)	Daily VMT Reduction vs No Build	203,000	394,800	438,700
B)	Annual VMT Reduction (A x 271)	55,000,000	106,990,800	119,000,000

Table 36. 2040 Auto Users - Annual VMT Savings per Alternative Compared to No Build

Source: Arup estimates based on CTPS data. Numbers were rounded.

Impacts to Rapid Transit

The CTPS model results suggest that in the build alternatives, as MBTA Commuter Rail service increases, MBTA rapid transit forecast ridership increases moderately. In the No Build alternative, the model forecasts that ridership on the Green, Red, Orange and Blue Lines will increase about 18% from today's ridership (to about 950,000 daily trips in 2040). For the South Station Expansion & All-Day Peak Service alternative, rapid transit ridership decreases by about 7,500 daily riders from the No Build alternative (less than 1% fewer passengers). For the NSRL All-Day Peak Service (Two-Track) alternative, rapid transit ridership decreases about 25,000 daily riders from the No Build (about 2.5% fewer passengers), and for the NSRL All-Day Peak Service (Four-Track) alternative, rapid transit ridership decreases by 32,000 daily riders (about 3.4% fewer passengers).

Compared to the No Build alternative, the CTPS model identifies a reduction in peak period rapid transit ridership as well – about 6,600 passengers, or about 4,000 passengers in the peak hour. The Orange Line is likely to experience the largest reduction, driven by the reduction in transfers from North Station to the southbound Orange Line in the mornings and northbound in the afternoons. The Orange Line has a policy capacity of about 850 passengers per train, and the reduction in demand could approach the equal of four full trains.

	No Build	South Station Expansion & All-Day Peak Service (No NSRL)	NSRL All-Day Peak Service (Two-Track)	NSRL All-Day Peak Service (Four-Track)
Daily Ridership	950,000	935,000	926,000	918,000
Difference from No Build (absolute)	-	-7,500	-24,000	-32,000
Difference from No Build (%)	-	-1.0%	-2.5%	-3.4%

Table 37. 2040 Rapid Transit Ridership per Alternative Compared to No Build

Source: Analysis based on CTPS data. Numbers were rounded.

Other cities have used or are using commuter rail systems to supplement crowded rapid transit lines, and the CTPS model indicates a similar potential for the MBTA with the NSRL project. More service on the MBTA Commuter Rail network, enhanced by the provision of tunnel service through Downtown Boston, could play a key role in alleviating rapid transit overcrowding in future years.

Quantification of benefits

The CTPS ridership forecasts provide the basis for further analysis of project benefits. Table 38 summarizes the mobility benefits by each build alternative.

The model also estimates the MBTA Commuter Rail emissions, which increase between alternatives because higher levels of service requires increased usage of diesel locomotives. The emissions results also consider that the Two-Track and Four-Track build alternatives have more electrified service than the No Build or South Station Expansion & All-Day Peak Service alternatives (impacting emissions). The results are shown in Table 39.

2040 Benefits	South Station Expansion & All-Day Peak Service (No NSRL)	NSRL All-Day Peak Service (Two-Track)	NSRL All-Day Peak Service (Four-Track)
Impacts on Commuter Rail Users			
Number of Riders (daily weekday)	195,000	225,000	250,000
Daily Travel Time Savings per Rider (mins.)	3	6.5	6.5
% Trips – Work Related	83%	83%	83%
% Trips – Non-work Related	17%	17%	17%
Number of Daily Vehicle Trips Shifted to Transit	20,100	47,215	52,500
Total Daily Travel Time Savings from New Commuter Rail Users Shifted from Auto (hrs)	34	77	85
Total Daily Travel Time Savings Adjusted for Occupancy (X 1.2) (hrs)	42	95	105
Roadway & Air Quality Impacts (daily)			
Total VHT Reduced Adjusted for Occupancy (hrs)	11,280	26,559	29,500
Total VMT Reduction	203,000	394,800	438,700
Total Vehicle CO2 Reduction (metric tons)	55	107	118
Other Assumptions			
Annualization Factor	271		
Vehicle Occupancy Rate (persons/vehicle) *	1.2		

Table 38: 2040 Benefits by Project Alternative, Compared to No Build

**From CTPS Model. Numbers have been rounded.*

7.3 Operational Efficiencies

Under the various service alternatives identified in Chapter 4, rail operations increase substantially, from about 16,400 weekday daily train revenue miles to about 51,500 miles for the NSRL All-Day Peak Service (Two-Track) alternative and 55,000 miles for the NSRL All-Day Peak Service (Four-Track) alternative.

With this substantial increase in service, the maintenance needs of the system both increase and maintenance availability decreases. The MBTA currently performs track maintenance during midday periods, and with all-day peak levels of service, these maintenance windows would need to shift to nighttime to accommodate required work. In addition, with more service, maintenance needs – including trackwork and equipment maintenance – will increase.

As a benefit, the need to shuttle trains to the Boston Engine Terminal (BET) on the north side of the rail system, usually via the existing Grand Junction branch, will be substantially reduced. Currently, about 14 trains a week are required to move between BET and the south side rail system.

MBTA shuttles about one train daily in each direction from BET to the south side rail system. Assuming 20 miles as an average length for this journey, the total annual cost for these moves is about \$2.5 million.

2040 Commuter Rail Emissions (in metric tons)	No Build	South Station Expansion & All-Day Peak Service (No NSRL)	NSRL All-Day Peak Service (Two- Track)	NSRL All-Day Peak Service (Four-Track)
CO2 Commuter Rail Emissions (daily)	125	325	290	335
% Diesel Locomotives in Fleet	100%	95%	68%	73%

Table 39. CO2 Commuter Rail Emissions by Project Alternative

Source: CTPS Travel Demand Model, rounded numbers

Weekly Trains	Number of Cars	Miles	Car Miles weekly	Car Miles Annually	Cost per Car Mile	Annual Cost
14	10	20	2,800	140,000	\$17	\$2.5 mil

Table 40: 2018 Weekly MBTA Commuter Rail Non-Revenue Miles

7.4 Economic Impacts

Land Redevelopment

Just as the NSRL project has the potential to change travel patterns, it also can have an impact on existing and potential land uses, creating opportunities for the development of new housing units and changes in the location and number of jobs in the Greater Boston area. Three parcels, totaling about 50 acres of land, could be redeveloped, as shown in Table 41.

The development potential is a function of the Project Alternative as described below:

- In the **South Station Expansion & All-Day Peak Service (No NSRL)** alternative there is limited opportunity for redevelopment. Neither North Station nor Widett Circle can be freed up for real estate development because these parcels would be needed to operate the system. In the case of the Fort Point US Post Office parcel, the SSX TREDIS® Methodology study performed in 2014 suggests that about 280 households and about 1,300 employees could be located on the site, which is shared with the South Station Expansion project proposals.
- In the **NSRL All-Day Peak Service (both Two-Track and Four-Track) alternatives** the real estate development potential is maximized, since all three parcels discussed above could be fully redeveloped. The total area for redevelopment is estimated at 48.8 acres.



Figure 61: Map of Parcel Locations

Estimations for the size of potential redevelopment relied on data from parcels that were recently developed and located in proximity to the parcels under analysis. The Hines Tower was used as a reference for the Fort Point US Post Office parcel, the Hub on Causeway development was used as a reference for North Station, and South Bay Town Center was used as a reference for Widett Circle.

In the case of the Fort Point US Post Office parcel, a maximum Floor Area Ratio (FAR) of 10 was used, based on the Planned Development Area for the South Station Air Rights Development Sub-Area. The proposed Hines Tower development footprint includes non-developable areas, which limits the maximum effective FAR.

Based on the FAR from the reference projects, the three parcels have a redevelopment potential of up to 15 million gross square feet (GSF). The number of jobs that could be accommodated per type of land use was based on data developed by the U.S. Green Building on building occupancies per building activity (sq.ft. per employee). The data suggest a median of 250 sq.ft. per employee for office uses and 550 sq.ft. per employee for commercial/retail. The results are shown in Table 43.

Parcel	Parcel Size	South Station Expansion & All-Day Peak Service (No NSRL)	NSRL All-Day Peak Service (both Two-Track and Four-Track)
Fort Point US Post Office	12 acres	~10%* of site	Developable
North Station	5.5 acres	Non-Developable	Developable
Widett Circle	31.3 acres	Non-Developable	Developable
Total	48.8 acres	1.2 acres	48.8 acres

Table 41: Development Potential per Alternative

Source: Project estimates. Note: *Based on information from South Station Expansion Project: TREDIS Methodology, September 3, 2014.

Parcel	Hines Tower* Area	Hub on Causeway	South Bay Town Center
Parcel Size (sq.ft.)	-	121,000	442,000
Development (sq.ft.)	-	1.9m	1.1m
Floor-Area Ratio (FAR)	10	15.6	2.5
Uses			
Residential	10%	29%	40% (475 units)
Office	78%	43%	0%
Commercial/Retail	12%	22%	26%
Other (Green Space/ Circulation/ Parking)	0%	6%	34%

Table 42. References for Land Redevelopment Estimates

Source: Based on publicly available information

As Table 44 shows, depending on the alternative, the potential for redevelopment ranges from about 1,300 job locations in the South Station Expansion & All-Day Peak Service (No NSRL) alternative, to about 15m of potential developable GSF under the NSRL All-Day Peak Service (both Two-Track and Four-Track) alternatives, accommodating about 28,000 jobs and almost 4,000 residential units.

Economic Impact of Construction and Operation Expenditures

The economic impacts of both the construction and operation expenditures of the NSRL project were estimated based on the input-output model (RIMS II) developed by the Bureau of Economic Analysis.

RIMS II is a regional economic model used to assess the potential economic impacts of various projects. The model produces multipliers that estimate the total impact of a project (new construction, tourism, etc.) on a region. It assumes that an initial change in economic activity results in a cascade of effects that stimulate other sectors in the economy. For example, building the NSRL project would lead to increased production of concrete. The increased production of concrete would lead to more mining and the workers hired due to the increase in economic activity would spend more in the region.

The Boston-Cambridge-Newton and MA-NH Metropolitan Statistical Area are considered the geographic coverage areas for this analysis. Type II

Parcel	Fort Point US Post Office *	North Station	Widett	Total
Total Potential Developable GSF	5.2 m	3.7m	5.6m	15m
Residential Units	520	1,050	2,380	3,950
Office Sq.ft.	4.0 m	1.6 m	0.0 m	5.6m
Retail/Commercial Sq.ft.	0.6 m	0.8 m	0.4m	2.9m
Number of Office Jobs	16,300	6,400	0	22,700
Number of Commercial/Retail Jobs	1,100	1,500	2,650	5,250
Total Jobs	17,400	7,900	2,650	27,950

Table 43: Development Potential per Parcel

Source: Estimates based on 2016 LEED Reference for Building Design and Construction, U.S. Green Building

Note: *Uses FAR of 10, the maximum currently permissible in the area. Rounded numbers.

Parcel	South Station Expansion & All-Day Peak Service (No NSRL)	NSRL All-Day Peak Service (both Two-Track and Four-Track)
Total Potential Developable GSF	N/A	15m
Number of Jobs	1,300*	27,950
Housing units	280*	3,950

Table 44: Development Potential per Alternative

Source: Estimates based on 2016 LEED Reference for Building Design and Construction, U.S. Green Building

*Based on information from South Station Expansion Project: TREDIS Methodology, September 3, 2014.

multipliers were used to quantify the direct, indirect and induced economic impacts of the construction and operating phases of the project, as shown in Table 45. Multipliers from the construction industry for the construction phase and from the rail industry for the operating phase were also used.

The metrics generated by RIMS include:

- The model output corresponds to total sales, the aggregation of all impacts on the economy (direct, indirect, and induced)
- The earnings multipliers measure the total change in local household earnings per dollar of final-demand change, in this case the construction and operating expenditure of each project alternative. Earnings consist of wages and proprietors' income, and the net earnings of sole-proprietors and partnerships.
- The employment multipliers measure the total change in the number of local jobs per dollar of final-demand change (construction and operating expenditure). Employment is measured in both full- and part-time jobs.
- The value-added multipliers measure the total change in local value added per dollar of impact/ final demand change construction and operating expenditure). The value added is comparable to regional measures of the gross domestic product.

As the RIMS II multipliers show, the construction industry has higher multipliers than the rail transportation industry. For each dollar spent on a construction project, \$1.72 is generated, whereas

Industry	Output (per USD)	Earnings (per USD)	Number of Jobs (per million USD)	Value Added (per USD)
Construction	1.72	0.50	9.25	0.95
Rail Transportation	1.59	0.36	5.60	0.87

Table 45: RIMS Type II Economic Multipliers

Source: RIMS II multipliers

for each dollar spent in the rail industry, \$1.59 is generated. This is not surprising as the construction industry is a sector with one of the highest cascade effects on the economy.

The resulting impacts for the construction and operating phases of the various NSRL project alternatives are shown in Tables 46 and 47. The economic impacts correspond to the capital expenditures during the construction phase and to the operating expenditures during the operating phase. The higher the expenditure on either the construction or the operating phases, the higher the economic impact. The NSRL All-Day Peak Service (Four-Track) alternative, with a construction cost of more than \$15bn, would generate an increase in the regional GDP of a similar size (\$14bn) and would create around 140,000 jobs within a seven-year period. In comparison, the South Station Expansion & All-Day Peak Service (No NSRL) alternative, with a construction cost of near \$3.7bn, would generate an increase in the regional GDP of \$3.5bn and would create around 34,000 jobs within a six-year period. The results of Table 46 have been obtained by multiplying the capital expenditure of each project alternative by the relevant multipliers.

The economic impact from operating expenditures suggest that the NSRL All-Day Peak Service (Four-Track) alternative would generate the highest impact, followed by the NSRL All-Day Peak Service (Two-Track) and the South Station Expansion & All-Day Peak Service (No NSRL) alternatives, given the respective sizes of their operating budgets.

	2018 USD (in millions)				
Project Alternatives	Capital Expenditure	Output	Earnings	Number of Jobs	Value Added
South Station Expansion & All-Day Peak Service (No NSRL)	3,700 (six-year construction phase)	6,350	1,860	34,240	3,500
NSRL All-Day Peak Service (Two-Track)	9,500 (seven-year construction phase)	16,300	4,770	87,900	9,000
NSRL All-Day Peak Service (Four-Track)	15,200 (seven-year construction phase)	26,086	7,629	140,655	14,400

Table 46: Total Economic Impact on Greater Boston - Construction Phase

Source: Estimates based on RIMS II

	2018 USD (in millions)				
Project Alternatives	Operating Expenditure	Output	Earnings	Number of Jobs	Value Added
South Station Expansion & All-Day Peak Service (No NSRL)	360	573	130	2,014	310
NSRL All-Day Peak Service (Two-Track)	503	801	181	2,815	440
NSRL All-Day Peak Service (Four-Track)	557	887	201	3,117	485

Table 47: Total Economic Impact on Greater Boston – Operations Phase

Source: Estimates based on RIMS II

7.5 Environmental Justice Analysis

Environmental justice (EJ) principles seek to “avoid, minimize or mitigate disproportionately high and adverse human health and environmental effects, including social and economic effects on minority populations and low-income populations” and to “prevent the denial or, reduction in, or significant delay in the receipt of benefits by minority and low-income populations.” Community participation is also a key principle.²⁴ Fair treatment of all people is considered paramount.

The NSRL project has the ability to either improve the quality of life and the economic status of minority and low-income communities, or to make it worse. Better transportation can enhance access to employment opportunities benefiting everyone, but more diesel trains adjacent to neighborhoods could make air quality in these areas worse.

To access the distribution of EJ-related economic benefits of the NSRL project, employment accessibility for three types of jobs – basic, retail and service (see descriptions below), is examined for EJ communities and compared against non-EJ communities. The purpose of the analysis is to determine if benefits are reasonably distributed among EJ and non EJ communities.

Based on an analysis with data developed in the CTPS modeling process, NSRL has the following economic impacts:

- **Accessibility:** The results suggest that in general, minority EJ and non-EJ communities improve their accessibility to jobs in all build alternatives

when compared against the No Build.

- **Distribution of benefits:** The results from the statistical test suggest that both minority EJ and non-EJ communities benefit from the project under the South Station Expansion & All-Day Peak Service (No NSRL) and NSRL All-Day Peak Service (Four-Track) alternatives, and neither is benefiting more than the other.
- Under the NSRL All-Day Peak Service (Two-Track) alternative, improvements in job accessibility tend to benefit more one group over the other. Accessibility improvements to retail and service jobs are benefiting slightly more minority EJ communities than non-EJ communities, whereas accessibility to basic jobs seems to improve slightly more for non-EJ communities

Definitions and Thresholds

Basic employment includes jobs that are typified as “blue collar”, which include but are not limited to jobs in manufacturing, laboratories, warehousing and transportation. Service employment includes jobs that are typified as “white collar”, which can include government, finance, insurance, and service jobs (excluding jobs in education). Retail employment refers to the jobs supporting the retail trade. The year 2040 employment projection has been adopted by the Boston Region MPO and used in its LRTP.

The study area for the EJ analysis uses the MBTA service area, defined earlier in this report and used in the MBTA’s 2017 Title VI report.²⁵

Two thresholds (race and ethnicity) were used to designate a TAZ an EJ community:

1. Minority EJ communities have minorities making up more than 28.19% of the population for that TAZ.
2. Low-Income EJ communities are where the median income is less than \$45,253 (60% of the MPO median income).

To estimate the impact all alternatives could have on employment accessibility by market segment (income and ethnicity), the analysis compared the change in number of jobs that could be reached by these market segments in all alternatives (build and No Build), using a fixed travel time of 40 minutes. Each alternative implemented some of the following changes to the commuter rail system that in turn changed the number of jobs that were accessible.

- In-vehicle travel time on the commuter rail lines
- Frequency
- Fares
- New Downtown Boston station location
- Connectivity of the north side to the south side of the rail network

A T test²⁶ determines whether the differences between EJ and non-EJ communities are statistically significant. The hypothesis of the test is that there is no difference between EJ and non-EJ communities in terms of the changes in accessibility generated by the NSRL project (in other words, the benefits are equally distributed).

	Basic Jobs		Retail Jobs		Service Jobs	
	EJ	Non-EJ	EJ	Non-EJ	EJ	Non-EJ
No Build	25,466	28,794	35,553	39,553	258,917	278,212
South Station Expansion & All-Day Peak Service (No NSRL)	25,597	28,876	35,675	39,502	260,387	278,246
Comparison of No Build vs. No NSRL	0.51%	0.28%	0.34%	-0.13%	0.57%	0.01%
t- test	0.8895		0.2730		0.9007	
(EJ vs non-EJ)	(statistically insignificant)		(statistically insignificant)		(statistically insignificant)	
	Basic Jobs		Retail Jobs		Service Jobs	
	EJ	Non-EJ	EJ	Non-EJ	EJ	Non-EJ
No Build	25,466	28,794	35,553	39,553	258,917	278,212
NSRL All-Day Peak Service (Two-Track)	25,720	29,127	36,089	39,968	262,766	280,301
Comparison of No Build vs. Two-Track	1.00%	1.16%	1.51%	1.05%	1.49%	0.75%
t- test	0.0003		0.0004		0.0022	
(EJ vs non-EJ)	(statistically significant)		(statistically significant)		(statistically significant)	
	Basic Jobs		Retail Jobs		Service Jobs	
	EJ	Non-EJ	EJ	Non-EJ	EJ	Non-EJ
No Build	25,466	28,794	35,553	39,553	258,917	278,212
NSRL All-Day Peak Service (Four-Track)	32,996	35,132	45,527	47,935	322,477	326,951
Comparison of No Build vs. Four-Track	.57%	22.01%	28.05%	21.19%	24.55%	17.52%
t- test (p value)	0.1855		0.2239		0.3901	
(EJ vs non-EJ)	(statistically insignificant)		(statistically insignificant)		(statistically insignificant)	

Table 48. Job Access for Minority EJ and Non-EJ Communities

Source: CTPS

	Basic Jobs		Retail Jobs		Service Jobs	
	EJ	Non-EJ	EJ	Non-EJ	EJ	Non-EJ
No Build	23,588	28,019	34,361	38,326	258,034	270,949
South Station Expansion & All-Day Peak Service (No NSRL)	23,857	28,082	34,707	38,281	261,079	271,106
Comparison of No Build vs. No NSRL	1.14%	0.22%	1.01%	-0.12%	1.18%	0.06%
T- test	0.2931		0.3473		0.7041	
(EJ vs non-EJ)	(statistically insignificant)		(statistically insignificant)		(statistically insignificant)	
	Basic Jobs		Retail Jobs		Service Jobs	
	EJ	Non-EJ	EJ	Non-EJ	EJ	Non-EJ
No Build	23,588	28,019	34,361	38,326	258,034	270,949
NSRL All-Day Peak Service (Two-Track)	23,750	28,347	34,742	38,832	261,644	273,789
Comparison of No Build vs. Two-Track	0.68%	1.17%	1.11%	1.32%	1.40%	1.05%
T- test	0.0023		0.0052		0.0067	
(EJ vs non-EJ)	(statistically significant)		(statistically significant)		(statistically significant)	
	Basic Jobs		Retail Jobs		Service Jobs	
	EJ	Non-EJ	EJ	Non-EJ	EJ	Non-EJ
No Build	23,588	28,019	34,361	38,326	258,034	270,949
NSRL All-Day Peak Service (Four-Track)	31,872	34,612	45,295	47,063	329,827	323,176
Comparison of No Build vs. Four-Track	35.12%	23.53%	31.82%	22.79%	27.82%	19.28%
T- test	0.8338		0.6399		0.5134	
(EJ vs non-EJ)	(statistically insignificant)		(statistically insignificant)		(statistically insignificant)	

Table 49. Job Access for Low-Income EJ and Non-EJ Communities

Source: CTPS

7.6 Air Quality Benefits

Air Quality Benefits: CO2 Emissions Reduction

Air quality benefits, measured as reductions in CO2 emissions, occur when there is a decrease in vehicle miles traveled. However, the increase in MBTA Commuter Rail service, assumed to be relying mainly on diesel locomotives, offsets reductions in CO2 emissions from driving, and thus air quality benefits are eliminated, as displayed in Table 50. If the NSRL project had included systemwide electrification, the emissions from diesel locomotives would be eliminated, but at a significant increase in capital costs for the project. Should the NSRL advance in a future in which the MBTA has already electrified the commuter rail network, the increased service levels would not increase emissions (as they do in this Feasibility Reassessment).

The Global Warming Solution Act sets statewide greenhouse gas (GHG) emission reduction goals of 10-25% below statewide 1990 GHG emission levels by 2020 and 80% below statewide 1990 GHG emission levels by 2050.²⁷ The Massachusetts Department of Environmental Protection (MassDEP) reports that, based on recently available data, 2014 GHG emissions in the state were 21% below the 1990 baseline level. In the transportation sector, statewide VMT has remained steady, despite a modest increase in population.²⁸

However, the continued use of diesel locomotives on the MBTA Commuter Rail impacts MassDOT

compliance with the desired GHG reductions, as discussed above. Potential mitigations are the introduction of alternative fuel sources, including potential battery-electric traction, as discussed in Chapter 3.

Source of Emissions	No Build	South Station Expansion & All-Day Peak Service (No NSRL)	NSRL All-Day Peak Service (Two-Track)	NSRL All-Day Peak Service (Four-Track)
Commuter Rail	125	323	292	336
Automobile	36,733	36,679	36,668	36,615
Total	36,858	37,002	36,960	36,951
Difference from No Build*	-	(144)	(102)	(93)

Table 50. 2040 Rail and Auto CO2 Emissions for Project Alternatives

Source: Based on CTPS travel demand model. *A positive number indicates net positive reductions in CO2 emissions



8. Preferred Alignment and Construction Technology

8. Preferred Alignment and Construction Technology

8.1 Purpose and Background

This chapter summarizes the recommended Preferred Alignment for the NSRL Feasibility Reassessment.

Three NSRL alignments were studied:

- Central Artery (Two- and Four-Track)
- South/Congress (Two-Track)
- Pearl/Congress (Two-Track)

It is noted that all alternatives share common elements, including similar portal locations and portal designs, impacts on Back Bay Station, and signal and junction improvements. For the purposes of comparison, it is assumed that train operations – speed, reliability, and schedules – are similar in all three alignments.

In addition, three different construction approaches were also studied (all of which employ tunnel boring machines):

- 29-foot-diameter single-track tunnel (requiring two parallel bores)
- 41-foot-diameter double-track tunnel
- 51-foot-diameter double-track tunnel

For the Central Artery Four-Track Alignment, two parallel 41-foot bored tunnels are assumed.

The Pearl/Congress alignment must use the 29-foot-diameter tunnel approach. Both the Central Artery and South/Congress can use either the 41-foot-diameter tunnel or the 51-foot-diameter tunnel.

The No Build and South Station Expansion and All-Day Peak Service alternatives are not assessed, as the Feasibility Reassessment is tasked with recommending the preferred NSRL alignment.

Implied in the selection of a preferred tunnel alignment is both a consideration of the construction technology (tunnel diameter, station construction) and the service efficacy (number of trains and passengers).

The previous 2003 NSRL study included a robust Evaluation of Alternatives; those alternatives included non-tunnel alternatives (such as more MBTA rapid transit service) and compared them to the rail project alternative. This Feasibility Reassessment compares various tunnel alignments, tunnel designs and service options (intensities of service) to each other and the surface (no tunnel) alternatives, and to a No Build alternative with maximum feasible train service provided at expanded terminals.

The Two-Track build alternatives “mix and match” different alignments with tunnel designs. The Four-Track build alternative is only paired with the 41-foot tunnel design:

Tunnel Alignment	Tunnel Design	Alternative Tunnel Design
Central Artery – 2 Tracks	41-foot-diameter bored tunnel; mined stations	51-foot-diameter bored tunnel; stations within tunnel bore
Pearl/Congress – 2 Tracks	29-foot-diameter bored tunnel; mined stations	None
South/Congress – 2 Tracks	51-foot-diameter bored tunnel; stations within tunnel bore	41-foot-diameter bored tunnel; mined stations

Table 51 – Two-Track Alignment Alternative

Tunnel Alignment	Tunnel Design	Alternative Tunnel Design
Central Artery – 4 Tracks	41-foot-diameter bored tunnel; mined stations	None

Table 52 – Four-Track Alignment Alternative

Capacity

All Two-Track alignments are assumed to have capacity for up to 24 trains per hour in each direction. In this analysis, it is assumed that two to three of those trains are Amtrak Regional services (other Amtrak services are assumed to terminate at South Station). That leaves 21-22 train “slots” per hour for MBTA services, however upstream constraints limit the actual throughput to 17 trains per hour, per direction from both the northern lines and the southern lines merging at Back Bay Station.

Upstream capacity constraints on the Old Colony Lines only allow about six trains per hour to enter into the tunnel. The Fairmount Line has more capacity – likely another six trains per hour; however, there is insufficient upstream capacity on the northern system to accept more trains beyond those already routed through Back Bay.

Note that in Chapter 4, the Two-Track and Four-Track alternatives required different line pairings to accommodate the additional lines coming through the South portal in the Four-Track alternative, therefore necessitating different levels of service. When comparing the Two- and Four-Track alternatives in this Chapter, the comparison is between the most robust service levels available for each.

Guiding Principles

As part of the Feasibility Reassessment, MassDOT adopted a set of Guiding Principles, designed to provide a framework for the design and review of the NSRL design concepts. These Principles, also discussed in Section 3.3, are as follows:

Primary Principles

1. Design a system to enable service patterns that support the MBTA Focus40 goals and objectives.
2. Increase the capacity of the MBTA's commuter rail network to bring commuters into Downtown Boston and Back Bay during peak commuting hours.
3. Improve the transit accessibility to employment opportunities in Boston's urban core, particularly for residents on the north side of the Boston metropolitan area.
4. Relieve congestion on the MBTA's rapid transit network (in particular on the Orange Line) by directly connecting commuters with their final destination.
5. Improve the MBTA's ability to efficiently maintain its rail fleet.

Secondary Principles

1. Reduce the physical footprint of rail layover facilities (both at the downtown terminals and elsewhere in the urban core), freeing these locations up for higher and better use.
2. Reduce the emissions associated with the commuter rail system in the urban core through the electrification of portions of the network.

8.2 Evaluation Objectives and Methodology

As each proposed alternative was assessed using a consistent and agreed upon methodology, it was also important to understand the priorities of the asset owner and the asset users (MassDOT and MBTA and Amtrak, respectively). The development of the Guiding Principles was a critical first step in this process. Following this, the process includes:

- Agreement on Evaluation Criteria
- Weighting for each criterion to best match the Guiding Principles
- Evaluation and scoring of each alternative against each criterion
- Application of the weighting to each criterion and development of the full score

Evaluation Categories

Pivoting from the Guiding Principles, this chapter proposes to evaluate the alignments and service plans in three broad categories:

- Economy
- Environment
- Equity

More detail on the actual criteria under these categories can be found in Appendix F.

Evaluation Process – Screening

A three-step screening process was used to evaluate and reduce the number of alternatives until a final recommendation was identified. Appendix F identifies 11 criteria grouped into three categories. All 11 criteria are used over the three screening steps, but only the relevant criteria are used in each screening (for example, Two-Track versus Four-Track has little difference in environmental impact).

First-Step Screening – Two- Versus Four-Track Alternatives

The first screen assesses Two-Track versus Four-Track alternatives. The relevant criteria include cost, use and selected impacts, as detailed in Table 53.

The construction cost for the Four-Track alternative (only viable on the Central Artery alignment) is about 90% greater than the mid-range Two-Track alternative. The total ridership is about 11% greater. The number of low-income households – owing to the ability of the Fairmount Line to use the tunnel – is greater with the Four-Track alternative and crowding reductions are also greater with the Four-Track alternative.

Taken together, and using the highest value as the basis for comparison, the screening scores are detailed in Tables 54 and 55.

Category	Criteria	Range	Weight	Total	Percentage
Economy	Estimated Construction Cost	1-5	10	10-50	70%
	Total Commuter Rail Weekday Riders	1-5	4	4-20	
Equity	Low-income Households Served	1-5	2	2-10	30%
	Reduced Crowding on MBTA Bus and Rapid Transit Lines in Low-income Areas	1-5	4	4-20	

Table 53: First-Step Screening Process

Category	Criteria	Range	Weight	Total
Economy	Estimated Construction Cost	4	10	40
	Total Commuter Rail Weekday Riders	4	4	16
Equity	Low-income Households Served	2	2	4
	Reduced Crowding on MBTA Bus and Rapid Transit Lines in Low-income Areas	1	4	4
TOTAL TWO-TRACK				64

Table 54: Two-Track First-Step Screening – Number of Tracks

Category	Criteria	Range	Weight	Total
Economy	Estimated Construction Cost	2	10	20
	Total Commuter Rail Weekday Riders	4.5	4	18
Equity	Low-income Households Served	3	2	6
	Reduced Crowding on MBTA Bus and Rapid Transit Lines in Low-income Areas	2	4	8
TOTAL FOUR-TRACK				52

Table 55: Four-Track First-Step Screening

Comparing the two scores, the recommendation is to advance a Two-Track alternative. While the Four-Track alternative slightly improves access to low-income households served (because of connecting the Fairmount Line, although the Two-Track alternative also provides good service to northern Gateway Cities) and reduces crowding on MBTA bus and rapid transit lines (because of its slightly greater coverage in the bus and subway service area) over the Two-Track alternative, the Two-Track alternative has a higher score because of its lower overall cost. As a result, the Four-Track Central Artery alternative is rejected. The Central Artery Two-Track alternative continues along with the other two Two-Track alternatives.

Second-Step Evaluation – Construction Technology

After first-step screening, the next step considers the appropriate construction technology, using the same criteria. The three tunneling options considered are:

- 29-foot-diameter single-track tunnel with mined stations
- 41-foot-diameter double-track tunnel with mined stations
- 51-foot-diameter double-track tunnel with stations within the tunnel diameter

The applicable criteria will be used to evaluate the three types of tunnel and project construction impacts:

Category	Criteria	Range	Weight	Total	Percentage
Economy	Estimated Construction Cost	1-5	10	10-50	70%
	Risks – Permitting, Construction Risk, and Operations Risk	1-5	2	2-10	
	Potential for Phasing	1-5	2	2-10	
Environment	Construction Impacts	1-5	2	2-10	30%
	Resilience in Disasters and Events	1-5	4	4-20	

Table 56: Second-Step Screening Process – Construction Technology

Tables 57 through 59 show the scores for the different-sized tunnel bores, as follows:

Category	Criteria	Range	Weight	Total
Economy	Estimated Construction Cost	4	10	40
	Risks – Permitting, Construction Risk, and Operations Risk	1	2	2
	Potential for Phasing	1	2	2
Equity	Construction Impacts	1	2	2
	Resilience in Disasters and Events	1	4	4
TOTAL 29-FOOT-DIAMETER BORE				50

Table 57: 29-Foot-Diameter Bore Screening

Category	Criteria	Range	Weight	Total
Economy	Estimated Construction Cost	5	10	50
	Risks – Permitting, Construction Risk, and Operations Risk	1	2	2
	Potential for Phasing	1	2	2
Equity	Construction Impacts	1	2	2
	Resilience in Disasters and Events	1	4	4
TOTAL 41-FOOT-DIAMETER BORE				60

Table 58: 41-Foot-Diameter Bore Screening

Category	Criteria	Range	Weight	Total
Economy	Estimated Construction Cost	4.5	10	45
	Risks – Permitting, Construction Risk, and Operations Risk	3	2	6
	Potential for Phasing	1	2	2
Equity	Construction Impacts	3	2	6
	Resilience in Disasters and Events	1	4	4
TOTAL 51-FOOT-DIAMETER BORE				63

Table 59: 51-Foot-Diameter Bore Screening

Based on the scoring, the 29-foot-diameter bored tunnel is eliminated, primarily due to its higher cost, relative to the other alternatives. The 41-foot- and 51-foot-diameter tunnels have close scores. The 41-foot-diameter tunnel is slightly less expensive, which is offset by its higher construction risks and impacts, compared to the 51-foot-diameter tunnel, where station construction is within the tunnel diameter and there is less impact on utilities within the city right-of-way (as most access is from adjacent parcels). The 51-foot-diameter tunnel scores slightly better than the 41-foot-diameter in overall scores.

For the purposes of the Feasibility Reassessment, the 51-foot-diameter tunnel is recommended; however, in any environmental document, the 41-foot-diameter tunnel should be considered as an alternative. The main tie-breaking benefit of the 51-foot-diameter tunnel is its reduced impacts on the street rights-of-way and other construction impacts and risk, which have high value in Boston. A downside of the 51-foot-diameter tunnel, aside from the higher cost, is that stations can be less appealing due to the constrained nature of constructing them within the tunnel diameter.

Third-Step Screening – Alignment

With construction method confirmed as the 51-foot-diameter tunnel, this approach is then applied to the three alignment studies. The Pearl/Congress alignment is not capable of using either the 41- or the 51-foot-diameter tunnels. As a result, that alignment is eliminated (there are also other concerns with the Pearl/Congress alignment, including connections to South Station and the ability to phase the system to an eventual four-track service). The remaining alignments are:

- Central Artery Two-Track
- South/Congress

The applicable criteria applied to the two remaining alignments are as follows:

Category	Criteria	Range	Weight	Total	Percentage
Economy	User Benefit (Downtown Catchment Areas)	1-5	8	8-40	70%
	Risks – Permitting, Construction Risk, and Operations Risk	1-5	4	4-20	
	Potential for Phasing	1-5	2	2-10	
Environment	Construction Impacts	1-5	1	1-5	15%
	Resilience in Disasters and Events	1-5	1	1-5	
	Increased Impacts of Commuter Rail Operations	1-5	1	1-5	
Equity	Low-income Households Served	1-5	2	2-10	15%
	Reduced Crowding on MBTA Bus and Rapid Transit Lines in Low-income Areas	1-5	1	1-5	

Table 60: Third-Step Screening Process - Alignment

The following tables show the scores for the Central Artery Two-Track Alignment and the South/Congress alignment:

Category	Criteria	Range	Weight	Total
Economy	User Benefit (Downtown Catchment Areas)	2	8	16
	Risks – Permitting, Construction Risk, and Operations Risk	1	4	4
	Potential for Phasing	1	2	2
Environment	Construction Impacts	1	1	1
	Resilience in Disasters and Events	1	1	1
	Increased Impacts of Commuter Rail Operations	2	1	2
Equity	Low-income Households Served	2	2	4
	Reduced Crowding on MBTA Bus and Rapid Transit Lines in Low-income Areas	2	1	2
TOTAL – CENTRAL ARTERY TWO-TRACK ALIGNMENT				32

Table 61: Central Artery Two-Track Alignment Screening

Category	Criteria	Range	Weight	Total
Economy	User Benefit (Downtown Catchment Areas)	3	8	24
	Risks – Permitting, Construction Risk, and Operations Risk	3	4	12
	Potential for Phasing	2	2	4
Environment	Construction Impacts	2	1	2
	Resilience in Disasters and Events	1	1	1
	Increased Impacts of Commuter Rail Operations	2	1	2
Equity	Low-income Households Served	2	2	4
	Reduced Crowding on MBTA Bus and Rapid Transit Lines in Low-income Areas	3	1	3
TOTAL – SOUTH/CONGRESS ALIGNMENT				52

Table 62: South/Congress Screening

8.3 Summary and Recommendation

Based on the scoring criteria, the South/Congress alignment is the preferred alternative, using the 51-foot-diameter bored tunnel. This alignment has the following advantages:

- More downtown Boston jobs are within easy walking distance of the alignment.
- The South Station placement (tunnel tracks and therefore egress to the street) is closer to existing commuters' jobs, compared to the station placement for the Central Artery Two-Track alignment.
- It makes connections to the Blue, Green and Orange Lines at the proposed commuter rail State-Haymarket Station, saving the cost of additional underground North or Central Stations to make these connections.
- There is less permitting risk, as the Fort Point Channel construction (which requires additional permits) is avoided in favor of a more inland route.
- It has slightly better resilience due to a more inland location that is further from sea level rise (not represented in the scoring, as in 50 years all locations are problematic).
- There is better potential for eventually creating a four-track system. The routing of Amtrak Northeast Corridor and Worcester Lines into the South/Congress alignment west of the existing South Station does not preclude eventually extending the Fairmount and Old Colony routes into a separate Central Artery Two-Track alignment. It should be noted that if the Central Artery Two-

Track alignment were selected and it was desired to allow for an eventual Four-Track service, the stations would have to be initially built for four tracks, substantially increasing costs. Envisioning a "South Station complex" with the initial NSRL on the west, surface tracks in the middle and eventual final phase NSRL on the east in the channel allows the eventual incorporation of the Fairmount and Old Colony Lines into a through service but without initial and significant expense.

The cost of the South/Congress alignment is estimated at about \$6.7bn in 2018 dollars (\$9.5m in 2028), with forecast ridership of about 225,000 daily commuter rail passengers. Following are two views – one of the South/Congress alignment and another showing its possible future extension to a four-track system.

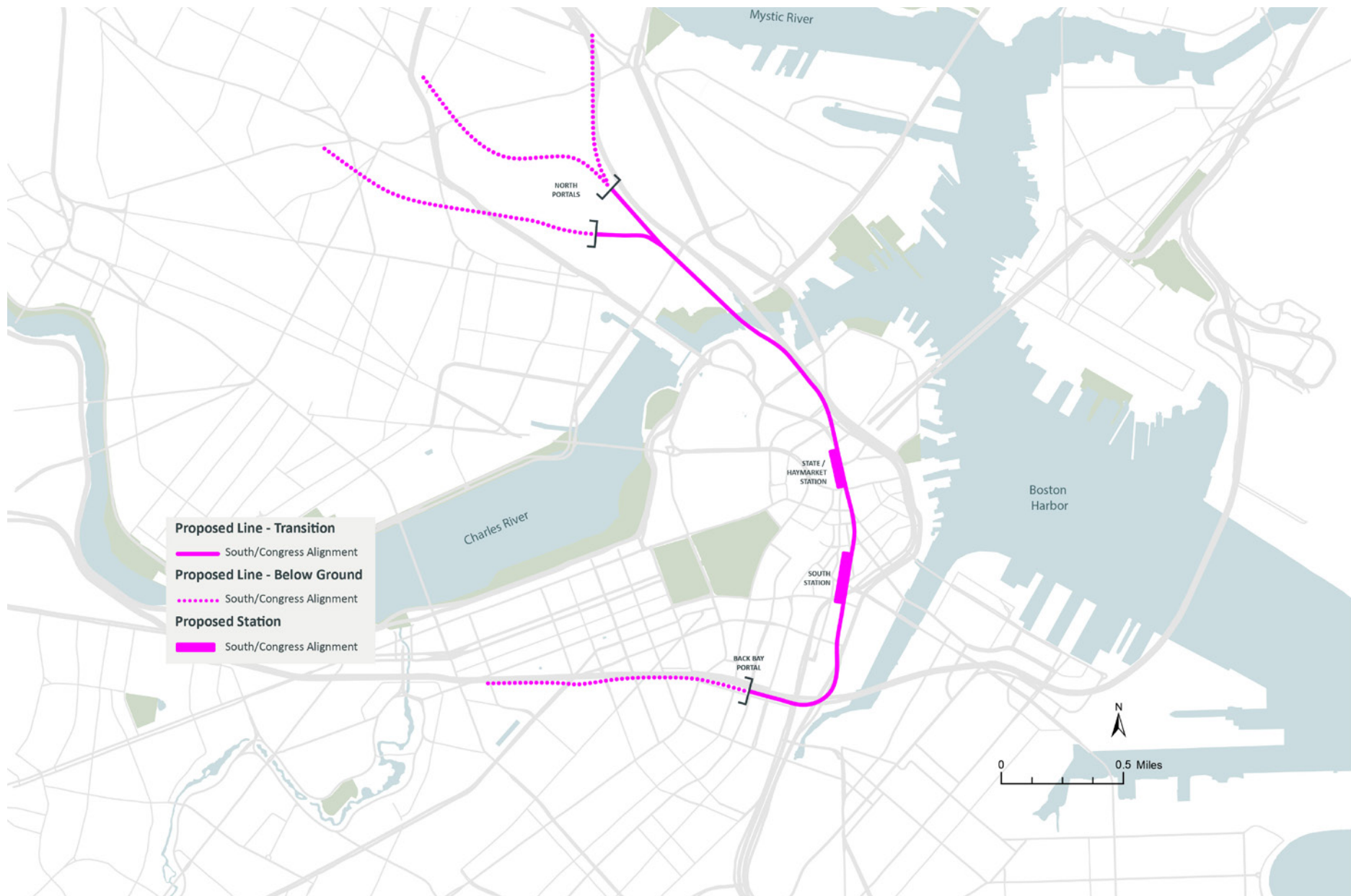


Figure 62: Full South/Congress Alignment

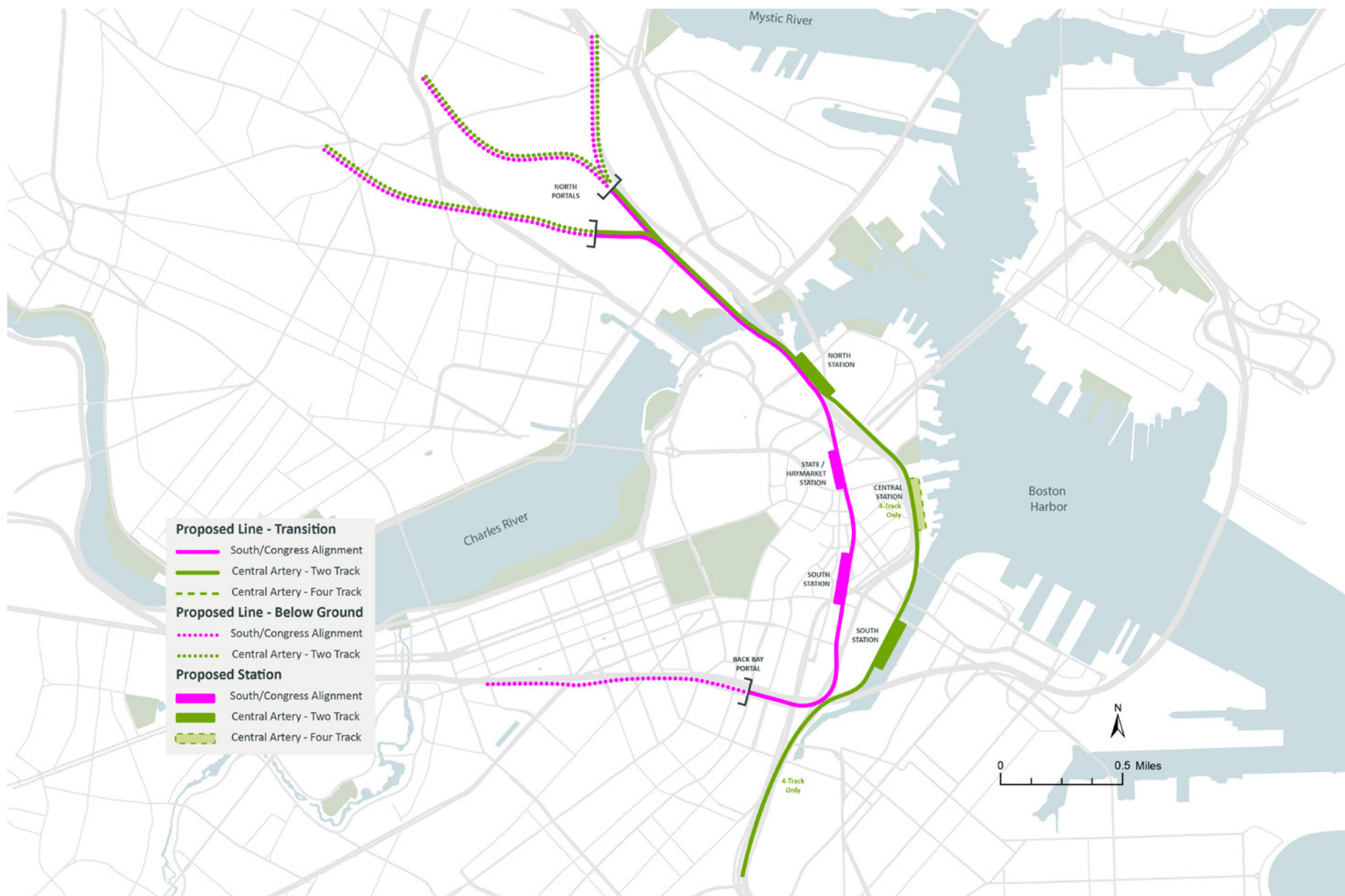


Figure 63: South/Congress Alignment with possible future extension

Views

Figures 64-68 show the South/Congress alignment overlaid on a street map of Boston. The segment maps offer more detail of the exact proposed path of the alignment underneath Boston, from its southern extent to the North portals.



Figure 64: Back Bay Portal to South Station (south end)

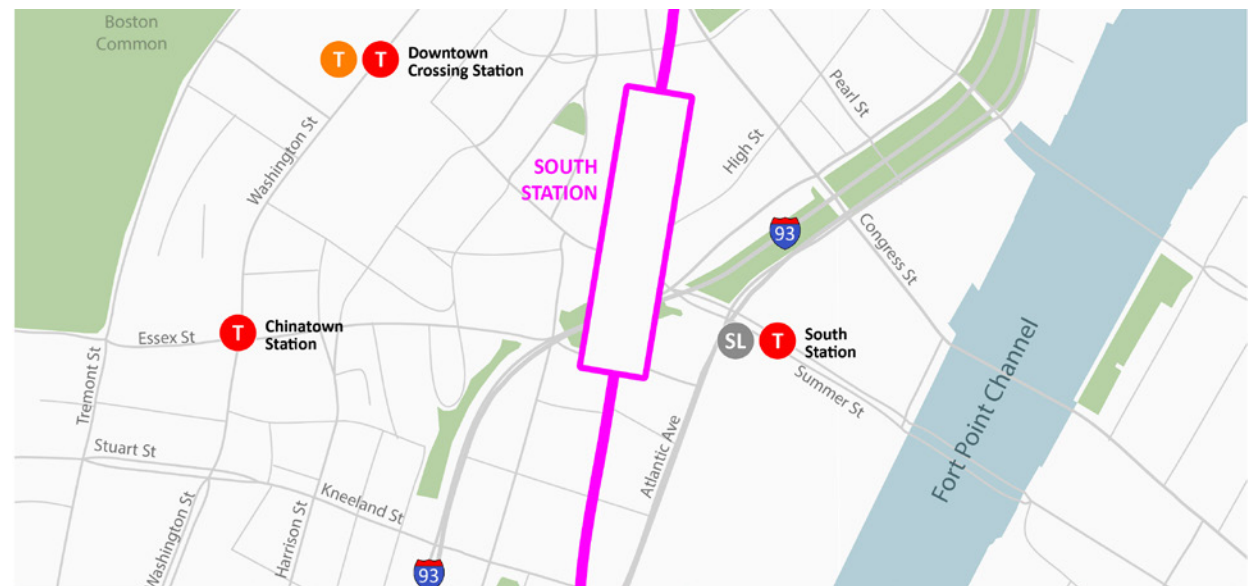


Figure 65: South Station (south end) to South Station (north end/Franklin Street)

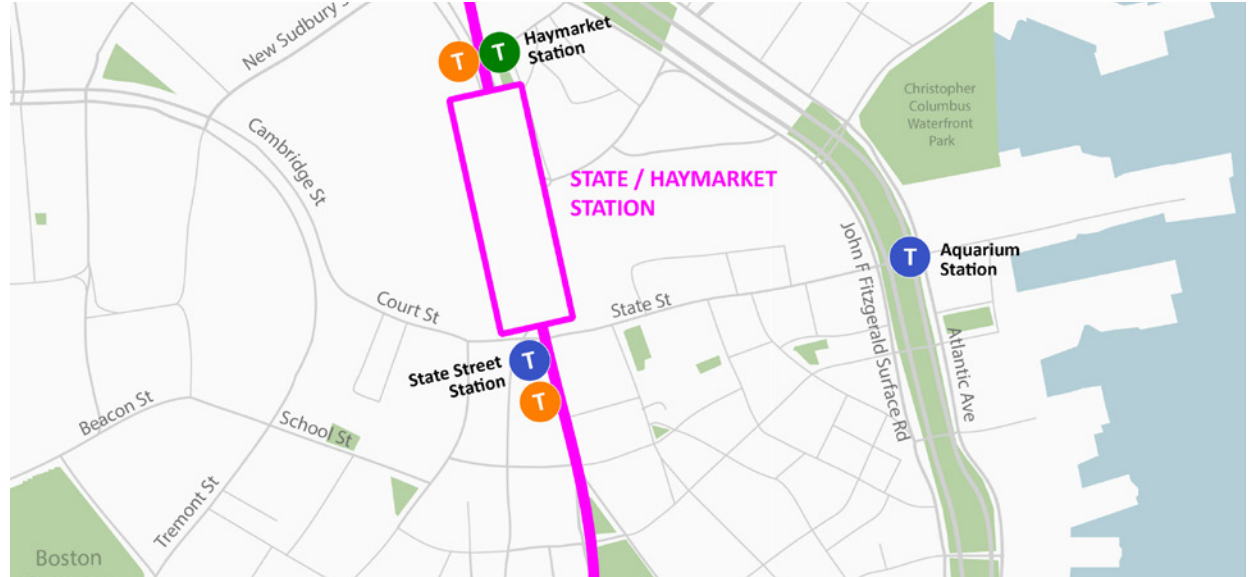


Figure 66: South Station (north end/Franklin Street) to State-Haymarket Station (New Sudbury Street)



Figure 67: State-Haymarket Station (New Sudbury Street) to North Station (Causeway Street)

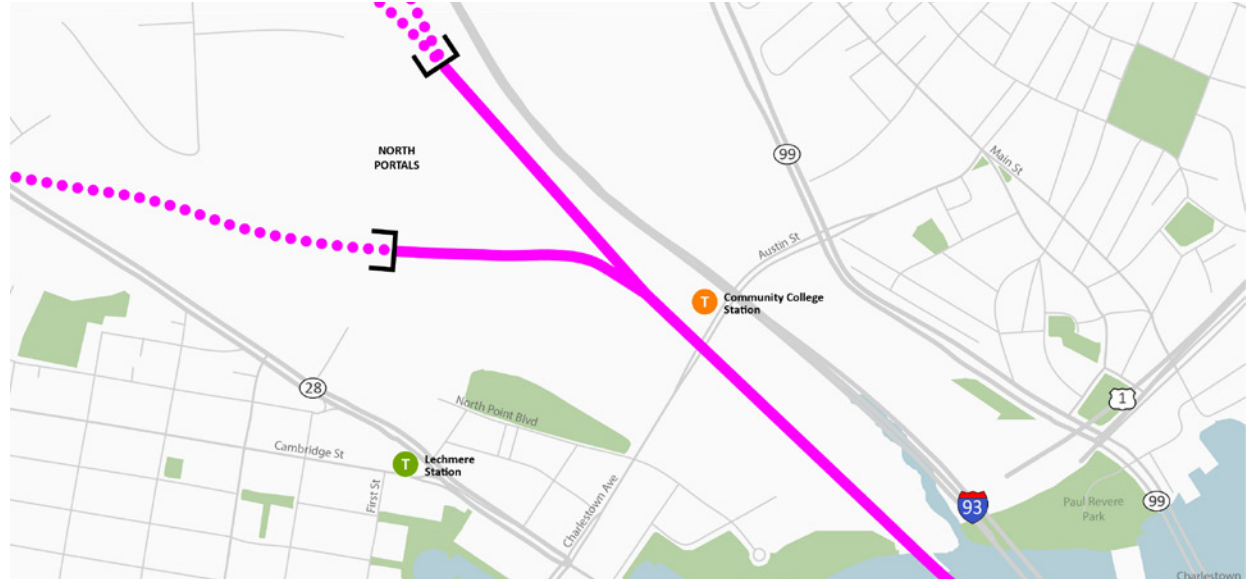


Figure 68: North Station (Causeway Street) to North Portals

Figure 69 shows a rendering of what the tunnel cross-section would look like for the South/Congress alignment, with the stacked tracks and stations within the 51-foot-diameter bore.

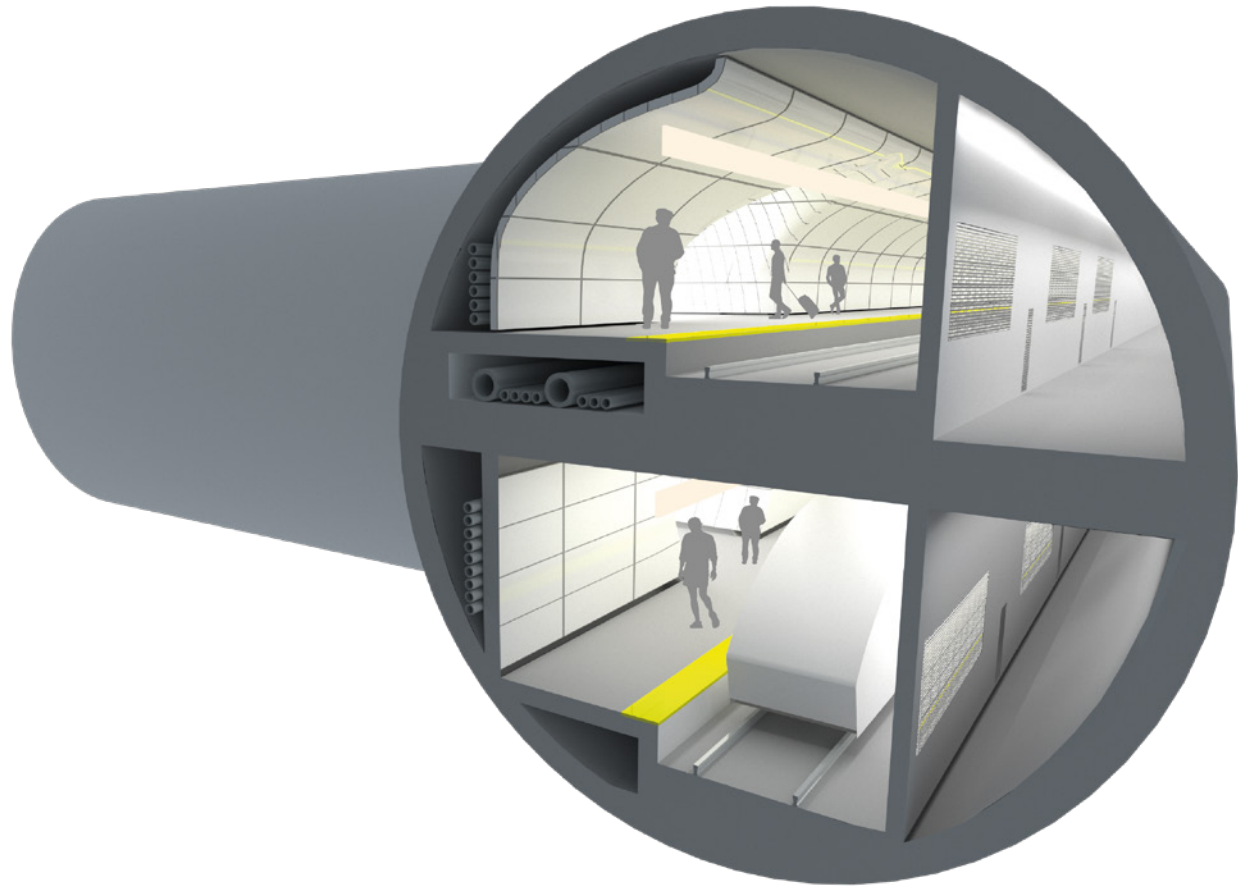


Figure 69: Cross-section of South/Congress Alignment



Photo Source: Katie Manning / Unsplash

9. Appendices



A. Citations

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- 2 Ridership Trends presentation, MassDOT Office of Performance Management and Innovation, February 27, 2017, [http://old.mbta.com/uploadedfiles/About the T/Board Meetings/M.%20Ridership%20Trends%20Final%20022717.pdf](http://old.mbta.com/uploadedfiles/About%20the%20T/Board%20Meetings/M.%20Ridership%20Trends%20Final%20022717.pdf)
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- 11 <https://www.mbtafocus40.com/>
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- 25 MBTA, Title VI Notice of Nondiscrimination Rights and Protections to Beneficiaries, <https://www.mbtta.com/policies/title-vi>
- 26 A T-test is a statistical procedure that determines whether the mean of a population significantly differs from a specific value (the "hypothesized mean") or from the mean of another population; the T-test is then used to determine whether the difference is statistically significant. In this test, the T-test used the following criteria for determining significance: If $p < 0.05$, the difference between an EJ community and a Non-EJ community is significant or likely to occur; If $p \geq 0.05$, the difference between an EJ community and a Non-EJ community is insignificant or unlikely to occur.
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B. Full List of Upstream Improvements

“Critical” interventions must be in place for a particular service plan to be implemented.

“Recommended” interventions reduce performance risks for a particular service plan and its associated level of service.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
All Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Recommended	Review of platform workings at locations where single platform face is provided on double track sections.	Provision of additional platform faces and related facilities.	The assumed track layout indicates locations where there is a single sided platform and it is understood that passengers can board/alight from trains on either line. While it may be feasible to do so with lower levels of services this approach may require reviewing with increases to the level of service. This is because an increased level of service may result in trains passing at locations whereby passengers are required to cross the track to board/alight trains. For the purposes of the scheduling no constraint on platform/boarding side is assumed, with trains operating on both lines (right-hand-side running)
All Lines	NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Removal of conflicts between trains entering the north & south tunnel portals and trains exiting the north & south tunnel portals to each route.	Grade separation between northbound and southbound services at each tunnel portal.	The service plans require 18-20tph trains in each direction through the tunnel core, it would not be feasible to cross opposing direction trains multiple times at this level service with an at-grade junction. This option potentially requires all four tracks running out towards Back Bay splitting between Worcester Line and Providence Lines (due short headways between services). However further schedule development may resolve some headway issues, but performance impact likely to be significant.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Fitchburg Line	South Station Expansion & All-Day Peak Service (No NSRL)	Critical	Additional terminal platform capacity	Provision of an additional platform	If turnaround times/junction margins cannot be reduced at Wachusett, then provision of an additional terminal platform is required.
Fitchburg Line	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	A review of signaling capability within the North Station throat, specifically looking at the ability to perform parallel crossings with same platform re-occupations. Requires at least 5-minute headways	Capability to support parallel crossing moves in the station throat to support 5-minute same platform re-occupation margins at North Station.	The schedule has been optimized around utilizing the minimum number of platforms at North Station. It is assumed the capability of 5-minute platform re-occupation is possible at North Station with a parallel crossing in the station throat. The ability to do so requires reviewing. Should it not be possible to do so then a review of the platform workings will be required.
Fitchburg Line	NSRL Regular Service (2-Track)	Critical	Additional terminal platform capacity	Provision of 1 additional terminal platform	The service plan requires 4 tph to start and terminate at Fitchburg. This is not possible from a single platform and therefore requires a minimum of 2 platforms (with a turnaround time/junction margin of less than 30 minutes). Note if the total turnaround time and junction margin can be reduced to 15 minutes then 1 platform could support 4 tph.
Fitchburg Line	NSRL Regular Service (2-Track)	Critical	Additional terminal platform capacity	Turnback siding for turning trains short	The service plan requires 4 tph to start and terminate at Fitchburg, This is not possible from a single platform and therefore this presents an alternative to the above. However, additional turnback facilities may be required if this option is taken forward, i.e. a turnback siding.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Fitchburg Line	NSRL Regular Service (2-Track)	Critical	Enhance signal capability	Enhancements to the signaling capability to support 8-minute headways	The service plan requires 4 tph on the Fitchburg Line. While theoretically 4 tph is a train every 15 minutes, it is not possible to support even frequencies due to constraints on the southern lines. A headway reduction is therefore required from the assumed 10 minutes to at least 8 minutes.
Fitchburg Line	NSRL Regular Service (2-Track)	Critical	Reduction of single line re-occupation margin at Waltham	Reduction of single line re-occupation margin at Waltham to at least 5 minutes	The service plan requires 4 tph in each direction over the single track line between Beaver Brook and Riverview. With each train occupying the single track line for 4 minutes (including 30 sec dwell at Waltham). The current assumption of 7 minutes would not feasibly support the train plan and requires reducing to at least 5 minutes.
Fitchburg Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional terminal platform capacity	Provision of 1 or 2 additional terminal platforms	The service plans require 6 tph to start and terminate at Fitchburg. This is not possible from a single platform and therefore requires a minimum of 2 platforms (with a turnaround time/junction margin of less than 20 minutes) or 3 platforms (max 30 minutes turnaround/junction margin).
Fitchburg Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional terminal platform capacity	Turnback siding for turning trains short	The service plans require 6 tph to start and terminate at Fitchburg. This is not possible from a single platform and therefore as an alternative to the above. However, additional turnback facilities may be required if this option is taken forward, i.e. a turnback siding.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Fitchburg Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Double track throughout Fitchburg Line	Doubling of the single track line between Beaver Brook and Riverview	The service plan requires 6 tph in each direction over the single track line between Beaver Brook and Riverview. With each train occupying the single track line for 4 minutes (including 30 sec dwell at Waltham) this would only leave a 1-minute margin between trains, which is unlikely to be feasible.
Lowell Line	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	A review of signaling capability within the North Station throat, specifically looking at the ability to perform parallel crossings with same platform re-occupations. Requires at least 5-minute headways	Capability to support parallel crossing moves in the station throat to support 5-minute same platform re-occupation margins at North Station.	The schedule has been optimized around utilizing the minimum number of platforms at North Station. It is assumed the capability of 5-minute platform re-occupation is possible at North Station with a parallel crossing in the station throat. The ability to do so requires reviewing. Should it not be possible to do so then a review of the platform workings will be required.
Lowell Line	South Station Expansion & All-Day Peak Service (No NSRL) & South Station Expansion & All-Day Peak Service (No NSRL) & NSRL All-Day Peak Service (4-Track)	Critical	Additional terminal platform capacity	Provision of an additional terminal platform at Lowell and reduction in turnaround time and platform re-occupation time to less than 20 minutes	The service plan requires 6 tph terminating at Lowell, which can be turned around using 2 platforms, provided the turnaround time and re-occupation margins can be reduced to less than 20 minutes per train.
Lowell Line	NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	A reduction of the signaling headway to 5 minutes is required on the Lowell Line	The schedule requires 6 tph Lowell Line services, plus it is assumed to accommodate 1 tph each way on the Wildcat Line. Due to the level of service, a headway reduction is required to support this through re-signaling.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	A review of signaling capability within the North Station throat, specifically looking at the ability to perform parallel crossings with same platform re-occupations. Requires at least 5-minute headways	Capability to support parallel crossing moves in the station throat to support 5-minute same platform re-occupation margins at North Station.	The schedule has been optimized around utilizing the minimum number of platforms at North Station. It is assumed the capability of 5-minute platform re-occupation is possible at North Station with a parallel crossing in the station throat. The ability to do so requires reviewing. Should it not be possible to do so then a review of the platform workings will be required.
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL)	Critical	Reduction in the number of return movements to Haverhill	Review yard capacities on the Haverhill Line	The single-line section between Reading Junction and Fells on the Haverhill Line presents a constraint on the network. As an alternative to the above options, it may be feasible to operate the peak direction of services from units kept in yards on the Haverhill Line instead of return off-peak movements. A review of the yard capacity is required to confirm the maximum number of units which can be stored.
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	A reduction of the signaling headway to 5 minutes is required	The level of service required in the service plan means that a signaling headway reduction from the base assumption of 10 minutes to at least 5 minutes is required.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	Improve signaling capability to support margins of at least 5 minutes	The single line section between Reading and Fells Junctions on the Haverhill Line presents a constraint on the network. It is potentially possible to develop a schedule around this constraint, however it would require a reduction of the margins at Fell Jn and Reading Junction.
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	Improve signaling capability to support a junction margin of at least 3½ minutes.	The single line section between Reading and Fells Junctions on the Haverhill Line presents a constraint on the network. It is potentially possible to develop a schedule around this constraint, however it would require a reduction of the margins at Reading and Fells Junctions.
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Doubling of Reading Junction and extension of siding.	Provision of a double junction and extension of siding at Reading Junction.	The single line section between Reading and Fells Junctions on the Haverhill Line presents a constraint on the network. As an alternative to the above options, provision of a double junction and extension of siding at Reading Junction would offer greater schedule flexibility and resilience.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Newburyport/ Rockport Lines	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	A review of signaling capability within the North Station throat, specifically looking at the ability to perform parallel crossings with same platform re-occupations. Requires at least 5-minute headways	Capability to support parallel crossing moves in the station throat to support 5-minute same platform re-occupation margins at North Station.	The schedule has been optimized around utilizing the minimum number of platforms at North Station. It is assumed the capability of 5-minute platform re-occupation is possible at North Station with a parallel crossing in the station throat. The ability to do so requires reviewing. Should it not be possible to do so then a review of the platform workings will be required.
Newburyport/ Rockport Lines	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	Review of the yard capacity at Newburyport and Rockport, should other enhancements to support full return movements not be delivered (i.e. Salem double-tracking).	Review yard capacities on the Newburyport/ Rockport Lines	Due to the network constraints outlined above, the resultant schedule has assumed a peak-direction flow of services, whereby 4 tph operate in the peak direction and 3 tph operate in the counter-peak direction, it is assumed 1 of the 4 counter-peak services operate between the MBTA CRMF depot and North Station. For the 3-hour AM and PM peaks, operating in such a manner means that to operate the peak-direction services, storage for at least 3 units is required before any return movements can be utilized (over the 3-hour peak).
Newburyport/ Rockport Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Recommended (Tier 3)	Double-track between McNall & Northey Point Junctions (between Swampscott and Salem stations)	Double-tracking between McNall and Northey Point Junctions (not in tunnel).	The single-line section between McNall and Northey Point Junctions (between Swampscott and Salem stations), further constrains the schedule. The number of trains that can be scheduled through the single-line section per hour is not sufficient to support the service plan alternatives. Double-tracking this section would remove this as a significant constraint on the network.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Newburyport/ Rockport Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	A reduction of the signaling headway to 5 minutes is required between North Station and Beverly	The level of service required in the service plan means that a signaling headway reduction from the base assumption of 10 minutes to at least 5 minutes is needed.
Worcester Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional platform capacity at Worcester and reduction of junction margins	Provision of an additional terminal platform at Worcester	The level of service required in the service plan means that capability for more than 1 train terminating at Worcester is required. Provision of a second terminal platform and 3-5 minute junction margins is required.
Needham Line	South Station Expansion & All-Day Peak Service (No NSRL)	Critical	Provision of an additional siding.	A siding is required at Highland Station, preferably incorporating the station into the siding	The availability of paths on the main line route results in trains passing on the Needham Branch at approximately the same location as Highland Station.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Needham Line	NSRL All-Day Peak Service (4-Track)	Critical	Additional sidings	Additional sidings	The level of service on the Needham Line requires provision of an additional siding between Highland and Bellevue Stations, in addition to requiring the existing sidings at Need and Rox Junctions. While it is possible to plan a service using these two sidings, there is an impact to journey times with waiting times between 3 and 6 minutes in each siding. Relocating the crossing sidings to existing stations could improve journey times.
Franklin Line	South Station Expansion & All-Day Peak Service (No NSRL)	Critical	Ability to include parallel arrival and departures to/from the Franklin Line at Readville	Provision of an additional crossover at the country-end of Readville to allow Franklin Line services to reach both platforms	The margin between a train from the Franklin Line and a train to the Franklin Line is less than 2 minutes. To resolve this, providing access to both Readville platforms via a new crossover would avoid conflicts between services.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Franklin Line	NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Ability to include parallel arrival and departures to/ from the Franklin Line at Readville and double-track to Endicott Station	Extension of double-track section between Endicott and Readville Stations into the two western side platforms at Readville. Provision of a parallel crossing so that simultaneous arrivals and departures at the city-end of the station can occur.	The margin between a train from the Franklin Line and a train to the Franklin Line is less than 2 minutes. To resolve this, providing access to both Readville platforms via a new crossover would avoid conflicts between services. A new crossover is also needed at Readville to enable parallel arrivals and departures.
Franklin Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional crossing sidings	Additional crossing sidings	Two additional crossing sidings are required for the Franklin Line, the first at approximately 20.5mi between Norfolk and Walpole West Junctions. The second (at approximately 26.5mi) is believed to be an existing siding named "Frank". Should this not be useable then a new siding is recommended at Franklin Station or towards the 28mi post. It is not possible for this schedule to make use of the Walpole siding without considerable impact to journey times.
Franklin Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Capability to turn back services at Dedham	A turnback crossover or siding	The service plans require 2 tph to terminate at Dedham, and facilities are required to support this.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Providence/ Stoughton Line	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	Review of platform workings at locations where a single platform face is provided on double- track sections.	Provision of additional platform faces and related facilities.	The assumed track layout indicates locations where there is a single-sided platform. It is understood that passengers can board/alight from trains on either line at these locations. While it may be feasible to do so with lower levels of service, this approach may require review once there are increases to the level of service. This is because an increased level of service may result in trains passing at locations whereby passengers are required to cross the track to board/alight trains. For the purposes of the schedule, no constraint on platform/boarding side is assumed, with trains operating on both lines (right-hand-side running)
Fairmount Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Infrastructure to support the turning back of services at Fairmount	Provision of an additional turnback crossover at Fairmount, or double-track to Readville	As an alternative to running all the Fairmount Line services to Readville, which requires interventions on the single-track line, it would be feasible to turn back some services at Fairmount instead. Or another alternative is to double-track the route to Readville with 2 platforms

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Old Colony Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional crossing locations on the Plymouth Line	Provision of an additional siding between Abington and Whitman Stations	The number of constraints coupled with the service plans necessitates an additional passing location for the Plymouth Line
Old Colony Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	A reduction of the single-line re-occupation margins on the Old Colony Lines	Provision of improved signaling capability to reduce the single line re-occupation margins to 3 minutes	The number of constraints coupled with the service plans necessitates an additional passing location on the Plymouth Line in addition to a reduction in re-occupation times for the single-line sections
Old Colony Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Recommended	Removal of single lines between JFK/UMass and Braintree Stations, to support improved network resilience and performance	Doubling of the single line tracks between JFK/UMass and Braintree Stations	The single-track lines between JFK/UMass Stations and Braintree Station and Adams Junction would be operating near maximum capacity and presents a significant risk to performance.

Table B1: Full List of Upstream Improvements

C. Ridership Model Description

Introduction

The Central Transportation Planning Staff (CTPS) develops and then employs a regional travel demand model for use in forecasting changes that could occur during the consideration of transportation proposals. For the North South Rail Link Study, CTPS provided technical support and developed ridership forecasts, as requested by the Massachusetts Department of Transportation (MassDOT). This document describes the modeling techniques and methodologies CTPS used when conducting an analysis of potential ridership.

Overview of the Modeling Process

To perform the analysis, CTPS used a four-step travel demand model, which was developed by CTPS and updated and improved over a number of years. The four steps of travel demand forecasting and in the CTPS model, described in more detail later in this Appendix, are trip generation, trip distribution, mode choice and then trip assignment.

The basis for ridership forecasts are transportation analysis zones (TAZs). TAZs are the geographic unit where trips are produced by households, and where trips are attracted to non-household destinations. TAZs are necessary for transportation modeling because they provide a level of estimation midway between the community and individual households. They are typically formed around small neighborhoods within a municipality or represent a group of blocks with similar land uses, such as residential, retail, service, or manufacturing. The TAZ structure was developed based on Census block groups, which have been subdivided in areas with high growth. Typically, TAZs in suburban and rural areas are relatively larger than TAZs in urban areas.

Outputs from the model include projected transit ridership on different transit modes (including estimates of passenger boardings on all the existing and proposed transit lines) and traffic volumes on the highway network. These are used as inputs to the planning and analysis process for the project. A flow chart of the modeling process is shown in Figure C1.

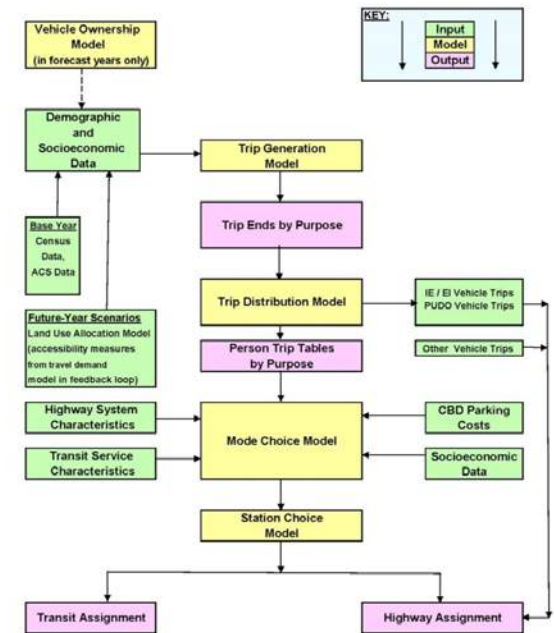


Figure C1: The CTPS Four-Step Travel Demand Modeling Process

ACS = American Community Survey. CBD = Central Business District. EI = External Internal.

IE = Internal External. PUDO = pick-up/drop-off.

Features of the CTPS Model – Data Inputs

General Modeling Characteristics

The CTPS travel demand forecasting model is an aggregate trip-based model. It is an aggregate model because it does not simulate the activities of each and every household (HH). Rather, the model simulates the travel behavior of groups of HHs, grouping them together based on common land use and access to travel modes. Geographically and physically, these groups make up the TAZs. These zones do not cross municipal boundaries and they are similar in terms of size (number of HHs or employers per zone) across the entire modeling region.

Modeled Area: The model encompasses all of Massachusetts, all of Rhode Island, and a portion of southern New Hampshire, as shown in Figure C52 below.

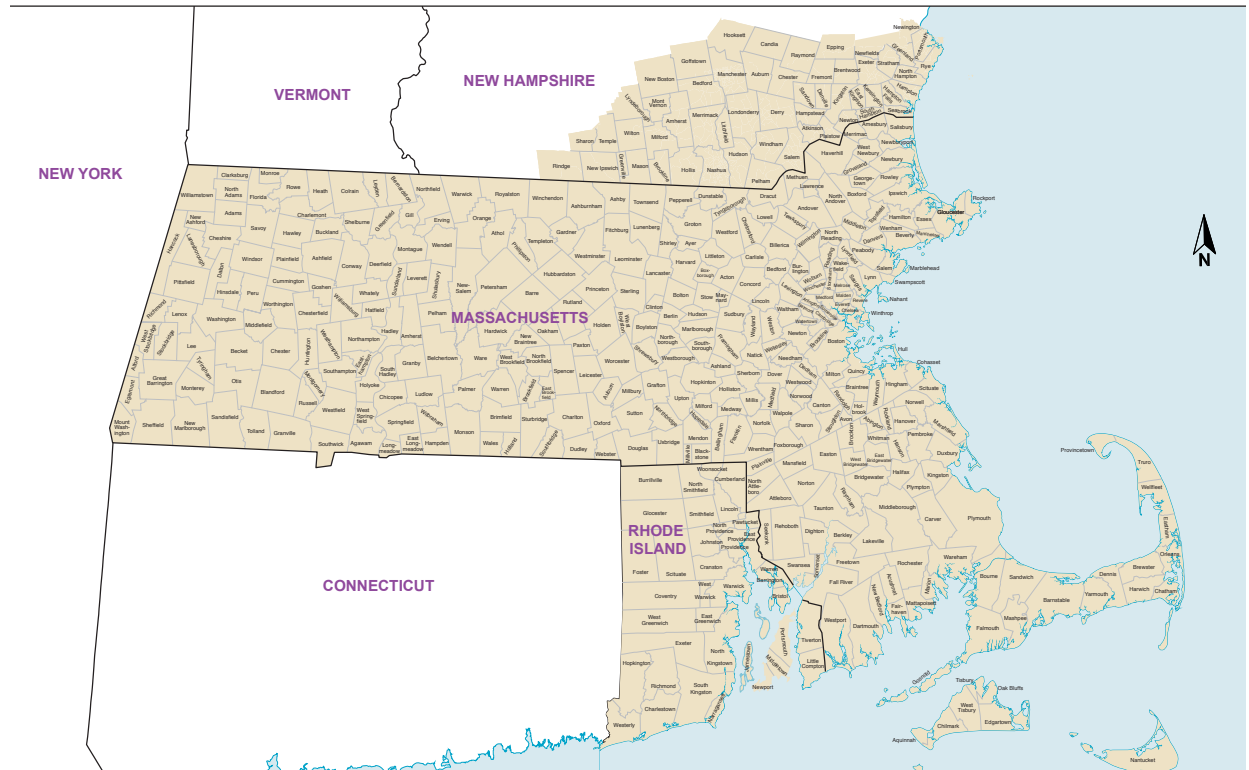


Figure C2: Extent of the CTPS Model Area

Zone System: The modeled area is divided into 5,739 internal TAZs. There are also 100 external stations around the periphery of the modeled area that account for travel between the modeled area and adjacent areas of Connecticut, New York, Vermont, and New Hampshire.

In a trip-based model, TAZs are the places where trips begin (trip producers) or end (trip attractors). TAZs can be as small as a single block (for example, in downtown Boston) or they can cover many square miles in rural areas. CTPS increased the number of TAZs in order to produce more reliable travel forecasts, but this comes at the cost of having to manage more data.

Modeling Years: Base and Future

The starting year for the model, referred to as the base year, is 2016, and incorporates data that CTPS uses in the model inputs. The model forecast extends to 2040.¹

Table C1 details the employment and population changes forecast for the Boston region.

¹ Central Transportation Planning Staff, Boston Region Metropolitan Planning Organization, Charting Progress to 2040: Long-Range Transportation Plan of the Boston Region Metropolitan Planning Organization, July 2015, http://www.ctps.org/data/pdf/plans/lrtp/charting/2040_LRTP_Full_final.pdf

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North Central	Haverhill	Inside	Malden	14,797	14,983	62,948	76,825
	Haverhill	Inside	Melrose	7,151	7,343	27,148	27,487
	Haverhill	Inside	Saugus	11,275	11,269	27,128	28,740
	Haverhill	Inside	Stoneham	7,785	7,821	21,340	21,543
	Haverhill	Inside	Wakefield	14,167	14,237	25,221	26,075
	Lowell	Inside	Lexington	20,134	22,504	31,972	34,717
	Lowell	Inside	Winchester	8,547	8,569	21,329	21,733
	Lowell	Inside	Woburn	34,373	34,600	39,246	42,679
	SUBTOTALS	INSIDE		118,229	121,326	256,332	279,799
	Haverhill	Outside	Reading	6,061	6,110	25,384	27,975
	Lowell	Outside	North Reading	6,855	7,040	15,295	16,954
	Haverhill	Outside	Lynnfield	4,388	4,877	11,473	11,520

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North Central	Haverhill	Outside	Andover	26,560	26,636	33,961	37,687
	Haverhill	Outside	Georgetown	2648	2651	8,501	9,442
	Haverhill	Outside	Groveland	910	911	6,683	7,572
	Haverhill	Outside	Haverhill	21,656	21,730	63,029	69,095
	Haverhill	Outside	Lawrence	26640	27014	80,210	88,691
	Haverhill	Outside	Merrimac	875	875	6,302	6,587
	Haverhill	Outside	Methuen	18,647	18,962	50,329	58,094
	Haverhill	Outside	North Andover	20883	21165	29,011	32,045
	Haverhill	Outside	West Newbury	879	882	4,179	4,341
	Lowell	Outside	Burlington	33,734	38,620	25,379	28,678
	Lowell	Outside	Wilmington	20,162	20,352	22,670	23,836
	Lowell	Outside	Billerica	23,779	23,011	40,661	43,583
	Lowell	Outside	Chelmsford	21,367	23,387	34,046	35,878

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North Central	Lowell	Outside	Dracut	5827	6286	29,769	32,042
	Lowell	Outside	Dunstable	275	250	3,225	3,652
	Lowell	Outside	Lowell	36,795	36,465	107,103	110,090
	Lowell	Outside	Tewksbury	15,067	15,717	29,246	31,397
	Lowell	Outside	Tyngsborough	4,641	5,028	11,523	12,614
	SUBTOTALS	OUTSIDE		298,649	307,969	637,979	691,773
	SUBTOTALS	NORTH CENTRAL		416,878	429,295	894,311	971,572
					3%		9%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North East	Newburyport/Rockport	Inside	Winthrop	4,155	4,182	17,512	17,311
	Newburyport/Rockport	Inside	Everett	15,562	17,041	45,099	60,434
	Newburyport/Rockport	Inside	Lynn	27,181	28,815	92,881	100,819
	Newburyport/Rockport	Inside	Manchester-by-the-Sea	2,022	2,037	5,112	5,021
	Newburyport/Rockport	Inside	Marblehead	6112	6138	19,775	20,515
	Newburyport/Rockport	Inside	Nahant	506	509	3,309	3,113
	Newburyport/Rockport	Inside	Peabody	27,536	27,739	52,998	58,884
	Newburyport/Rockport	Inside	Revere	8,501	8,877	55,841	73,696
	Newburyport/Rockport	Inside	Salem	18,980	20,027	42,433	45,390

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North East	Newburyport/Rockport	Inside	Swampscott	4,061	4,081	13,737	14,193
	Newburyport/Rockport	Inside	Chelsea	16,919	17,136	36,657	42,054
	SUBTOTALS	INSIDE		131,535	136,582	385,354	441,430
	Newburyport/Rockport	Outside	Beverly	24,386	24,815	40,051	42,404
	Newburyport/Rockport	Outside	Rockport	2,397	2,397	6,907	6,813
	Newburyport/Rockport	Outside	Topsfield	2,530	2,536	5,884	5,849
	Newburyport/Rockport	Outside	Wenham	1,270	1,326	4,730	4,474
	Newburyport/Rockport	Outside	Danvers	21,992	22,356	27,585	31,043
	Newburyport/Rockport	Outside	Essex	1,605	1,610	3,591	3,737

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North East	Newburyport/Rockport	Outside	Gloucester	13,013	13,228	28,626	27,607
	Newburyport/Rockport	Outside	Hamilton	1,973	1,979	7,670	7,602
	Newburyport/Rockport	Outside	Ipswich	5,325	5,349	13,207	13,820
	Newburyport/Rockport	Outside	Middleton	5,361	5,494	9,416	10,786
	Newburyport/Rockport	Outside	Amesbury	5,297	5,305	16,366	17,290
	Newburyport/Rockport	Outside	Boxford	1,254	1,260	7,650	7,758
	Newburyport/Rockport	Outside	Newbury	1,729	1,731	6,533	6,680
	Newburyport/Rockport	Outside	Newburyport	12,394	12,520	17,451	18,673
	Newburyport/Rockport	Outside	Rowley	2,545	2,555	6,042	6,638

Community Information				Total employment		Total population	
Area	Rail line	Inside or outside ma-128	Town/city	2016	2040	2016	2040
North East	Newburyport/ Rockport	Outside	Salisbury	3,577	3,643	8,479	9,115
	SUBTOTALS	OUTSIDE		106,648	108,104	210,188	220,289
	SUBTOTALS	NORTH EAST		238,183	244,686	595,542	661,719
					3%		11%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North West	Fitchburg	Oustide	Petersham	123	123	1,260	1,350
	Fitchburg	Inside	Somerville	26,188	32,837	81,450	101,971
	Fitchburg	Inside	Waltham	56,175	59,401	62,556	70,009
	Fitchburg	Inside	Arlington	8,764	8,789	43,414	45,159
	Fitchburg	Inside	Belmont	7,277	7,305	25,367	27,977
	Fitchburg	Inside	Cambridge	113,070	123,395	109,486	123,808
	Fitchburg	Inside	Harvard	5,844	11,444	6,513	6,700
	SUBTOTALS	INSIDE		217,441	243,294	330,046	376,974
	Fitchburg	Outside	Phillipston	168	158	1,694	1,600
	Fitchburg	Outside	Royalston	121	113	1,238	1,150
	Fitchburg	Outside	Templeton	1,720	1,649	8,734	10,975
	Fitchburg	Outside	Wayland	3,845	3,934	12,651	12,395

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North West	Fitchburg	Outside	Westminster	2,568	2,398	7,414	7,445
	Fitchburg	Outside	Weston	6,646	6,665	11,297	12,053
	Fitchburg	Outside	Shirley	2,262	2,271	7,639	8,650
	Fitchburg	Outside	Stow	2,441	2,583	6,757	7,421
	Fitchburg	Outside	Sudbury	6,808	6,869	17,344	17,303
	Fitchburg	Outside	Townsend	2,072	1,998	8,971	7,900
	Fitchburg	Outside	Winchendon	1,636	1,549	10,625	11,175
	Fitchburg	Outside	Pepperell	1,855	1,759	11,588	12,553
	Fitchburg	Outside	Westford	12,034	13,832	22,260	25,105
	Fitchburg	Outside	Abington	4,420	4,704	17,032	20,382
	Fitchburg	Outside	Barre	1230	1332	5,534	5,936
	Fitchburg	Outside	Princeton	780	811	3,514	3,828
	Fitchburg	Outside	Acton	10,779	10811	22,315	24,253

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North West	Fitchburg	Outside	Ashburnham	1019	932	6,302	6,900
	Fitchburg	Outside	Ashby	282	274	3,166	3,313
	Fitchburg	Outside	Athol	3,379	3,299	12,011	14,700
	Fitchburg	Outside	Ayer	4,807	4,816	7,499	7,700
	Fitchburg	Outside	Bolton	2,510	2,514	4,982	5,177
	Fitchburg	Outside	Boxborough	2,082	2,180	4,893	4,730
	Fitchburg	Outside	Carlisle	1,021	1,021	4,739	4,692
	Fitchburg	Outside	Clinton	4,902	4,907	14,032	15,200
	Fitchburg	Outside	Concord	13,935	14,591	17,795	18,497
	Fitchburg	Outside	Fitchburg	12,740	12,598	41,038	42,340
	Fitchburg	Outside	Gardner	8,255	8,023	19,909	17,600
	Fitchburg	Outside	Groton	4361	4363	10,903	12,042
	Fitchburg	Outside	Hubbardston	501	484	4,628	5,480

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North West	Fitchburg	Outside	Hudson	8,293	8,751	19,548	20,807
	Fitchburg	Outside	Leominster	17,690	17,498	40,210	36,500
	Fitchburg	Outside	Lincoln	2,748	2,755	6,199	5,900
	Fitchburg	Outside	Littleton	6,012	6,969	9,189	10,376
	Fitchburg	Outside	Lunenburg	2,262	2,199	10,364	10,480
	Fitchburg	Outside	Bedford	16,114	16,564	13,823	16,093
	Fitchburg	Outside	Lancaster	1,962	1,970	8,464	9,600
	Fitchburg	Outside	Maynard	3,201	3,210	10,158	10,208
	SUBTOTALS	OUTSIDE		179,461	183,354	446,459	468,459
	SUBTOTALS	NORTH WEST		396,902	426,648	776,505	845,433
					7%		9%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South Central	Franklin	Inside	Dedham	14,895	15,162	25,563	28,539
	Franklin	Outside	Hopedale	1,592	1,636	6,122	6,809
	Franklin	Outside	Norwood	24,127	24,435	29,076	30,771
	Franklin	Outside	Walpole	10,693	11,089	24,646	26,910
	Franklin	Outside	Westwood	11,505	12,374	14,571	15,253
	Franklin	Outside	Mendon	1362	1487	5,986	6,416
	Franklin	Outside	Millville	290	300	3,274	3,522
	Franklin	Outside	Blackstone	1,148	1,457	9,313	10,213
	Franklin	Outside	Uxbridge	3,257	3,689	14,247	17,022
	Franklin	Outside	Bellingham	5,747	5,759	16,797	17,912
	Franklin	Outside	Franklin	15,566	17,567	32,029	34,241
	Franklin	Outside	Medfield	3,267	3,298	11,635	11,558

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South Central	Franklin	Outside	Medford	18,828	19,254	57,776	64,380
	Franklin	Outside	Medway	3,430	3,433	12,649	12,764
	Franklin	Outside	Milford	18,962	19,856	29,102	32,978
	Franklin	Outside	Millis	2,436	2,486	7,678	7,260
	Franklin	Outside	Milton	7,442	7,463	27,385	28,917
	Franklin	Outside	Norfolk	2,642	2,647	11,431	11,844
	Franklin	Outside	Wrentham	5,885	6,158	10,952	11,257
	Providence/ Stoughton	Outside	Canton	28,097	28,444	22,096	24,190
	Providence/ Stoughton	Outside	Foxborough	9,938	11,608	16,992	17,434
	Providence/ Stoughton	Outside	Sharon	5,188	5,291	17,462	18,474
	Providence/ Stoughton	Outside	Stoughton	14,505	15,510	27,020	27,209

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South Central	Providence/Stoughton	Outside	Easton	10,597	10,737	23,135	23,019
	Providence/Stoughton	Outside	Attleboro	16,896	18,409	44,823	48,889
	Providence/Stoughton	Outside	Dighton	1,823	1,873	7,208	7,422
	Providence/Stoughton	Outside	Fairhaven	6,028	5,982	16,146	16,625
	Providence/Stoughton	Outside	Mansfield	11,162	12,140	23,058	24,157
	Providence/Stoughton	Outside	Marion	2,183	2,140	4,991	5,140
	Providence/Stoughton	Outside	North Attleborough	11,291	12,293	29,328	31,624
	Providence/Stoughton	Outside	Norton	6,078	6,690	19,277	20,617
	Providence/Stoughton	Outside	Plainville	3,934	4,653	8,578	9,511

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South Central	Providence/Stoughton	Outside	Rehoboth	1,687	1,719	11,808	12,159
	Providence/Stoughton	Outside	Seekonk	8,301	8,643	13,958	14,371
	Providence/Stoughton	Outside	Swansea	5,426	5,676	16,138	16,618
	SUBTOTALS	OUTSIDE		281,313	296,196	626,687	667,486
	SUBTOTALS	SOUTH CENTRAL		296,208	311,358	652,250	696,025
					5%		7%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Old Colony	Inside	Quincy	36,820	41,942	96,630	111,114
	Old Colony	Outside	Braintree	23,712	23,992	37,465	44,036
	Greenbush	Outside	Norwell	8,426	8,437	10,645	11,196
	Greenbush	Outside	Scituate	4,055	4,078	18,022	19,347
	Greenbush	Outside	Weymouth	22,402	22,764	54,168	56,420
	Greenbush	Outside	Cohasset	3,314	3,497	8,049	10,306
	Greenbush	Outside	Hingham	14,889	15,361	22,521	23,426
	Greenbush	Outside	Hull	1,888	1,893	10,095	9,376
	Greenbush	Outside	Marshfield	8,704	9,741	25,235	26,097
	Kingston/ Plymouth	Outside	Rockland	7,711	7,740	17,486	17,468
	Kingston/ Plymouth	Outside	Hanover	7,270	7,286	14,035	14,551
	Kingston/ Plymouth	Outside	Duxbury	3,571	3,594	15,108	18,622

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Kingston/ Plymouth	Outside	Pembroke	5,006	5,040	18,141	15,472
	Kingston/ Plymouth	Outside	Halifax	1,446	1,461	7,513	7,448
	Kingston/ Plymouth	Outside	Hanson	2,146	2,149	10,524	11,351
	Kingston/ Plymouth	Outside	Kingston	6,892	7,806	13,060	14,630
	Kingston/ Plymouth	Outside	Plymouth	26458	28,368	59,142	64,342
	Kingston/ Plymouth	Outside	Plympton	832	1,130	2,860	3,002
	Kingston/ Plymouth	Outside	Whitman	2,707	2,738	14,773	15,235
	Kingston/ Plymouth	Outside	Carver	2,777	3,139	11,819	12,911
	Middleborough/ Lakeville	Outside	Randolph	8,233	8,263	33,240	37,119
	Middleborough/ Lakeville	Outside	Holbrook	2,972	2,990	10,850	11,110

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Middleborough/Lakeville	Outside	Avon	5,294	5,389	4,362	4,327
	Middleborough/Lakeville	Outside	Bridgewater	8,661	9,117	26,859	27,456
	Middleborough/Lakeville	Outside	Brockton	37,765	38,276	95,513	97,886
	Middleborough/Lakeville	Outside	East Bridgewater	3,282	3,503	14,212	14,967
	Middleborough/Lakeville	Outside	West Bridgewater	7,734	8,196	7,070	7,559
	Middleborough/Lakeville	Outside	Acushnet	1226	1296	10,480	10,792
	Middleborough/Lakeville	Outside	Berkley	571	616	6,521	6,715
	Middleborough/Lakeville	Outside	Dartmouth	16,030	17,022	34,616	35,645
	Middleborough/Lakeville	Outside	Fall River	35,017	35,584	90,383	91,557
	Middleborough/Lakeville	Outside	Freetown	4,201	4,658	9,022	9,289

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Middleborough/Lakeville	Outside	Lakeville	3,174	3,620	10,889	11,909
	Middleborough/Lakeville	Outside	Mattapoisett	1,750	1,763	6,148	6,331
	Middleborough/Lakeville	Outside	Middleborough	8,456	9,514	24,491	28,130
	Middleborough/Lakeville	Outside	New Bedford	35,894	35,332	96,710	99,580
	Middleborough/Lakeville	Outside	Raynham	8515	9355	14,290	16,552
	Middleborough/Lakeville	Outside	Rochester	768	763	5,322	5,479
	Middleborough/Lakeville	Outside	Somerset	4,482	4,517	18,477	19,026
	Middleborough/Lakeville	Outside	Taunton	24,542	26,971	56,404	59,958
	Middleborough/Lakeville	Outside	Wareham	8,961	9,131	22,199	22,857

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Middleborough/ Lakeville	Outside	Westport	3,304	3,206	15,798	17,775
	SUBTOTALS	OUTSIDE		385,038	399,296	984,517	1,037,255
	SUBTOTALS	SOUTH EAST		421,858	441,238	1,081,147	1,148,369
					5%		6%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
West	Worcester	Inside	Brookline	20,402	20,739	62,015	72,613
	Worcester	Inside	Newton	47,995	49,184	86,416	90,182
	Worcester	Inside	Watertown	18,296	18,437	33,040	36,901
	SUBTOTALS	INSIDE		86,693	88,360	181,471	199,696
	Needham	Outside	Dover	884	888	5,482	5,410
	Needham	Outside	Needham	18,209	18,441	29,251	31,623
	Worcester	Outside	Auburn	10,071	10,684	16,603	17,814
	Worcester	Outside	Wellesley	21825	21959	27,873	27,403
	Worcester	Outside	Berlin	462	497	3,177	4,336
	Worcester	Outside	Boylston	1671	1727	4,519	5,051
	Worcester	Outside	Brookfield	494	498	3,479	3,745
	Worcester	Outside	Charlton	3824	4,394	13,534	15,380
	Worcester	Outside	Douglas	874	1,045	8,788	9,820

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
West	Worcester	Outside	Dudley	2842	3107	11,674	12,503
	Worcester	Outside	East Brookfield	396	401	2,235	2,382
	Worcester	Outside	Grafton	4134	4463	18,792	22,390
	Worcester	Outside	Hardwick	392	395	3,066	3,289
	Worcester	Outside	Holden	3,561	3,873	17,945	19,862
	Worcester	Outside	Leicester	2,228	2,416	11,243	12,048
	Worcester	Outside	Millbury	5093	5489	13,749	15,319
	Worcester	Outside	New Braintree	239	243	1,019	1,071
	Worcester	Outside	North Brookfield	901	916	4,800	5,154
	Worcester	Outside	Northborough	6,245	7,157	14,973	17,836
	Worcester	Outside	Northbridge	5372	6233	16,424	18,855
	Worcester	Outside	Oakham	211	225	1,942	2,053
	Worcester	Outside	Oxford	4266	4690	14,164	15,601

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
West	Worcester	Outside	Paxton	834	914	4,970	5,493
	Worcester	Outside	Rutland	1,096	1,220	8,332	9,543
	Worcester	Outside	Shrewsbury	13,135	14,068	36,914	41,171
	Worcester	Outside	Southbridge	5,941	6,876	17,030	17,814
	Worcester	Outside	Spencer	3,079	3,343	11,997	12,915
	Worcester	Outside	Sturbridge	4,711	5,186	9,949	12,392
	Worcester	Outside	Sutton	2,203	2,350	9,263	10,213
	Worcester	Outside	Upton	1,170	1,597	8,150	10,357
	Worcester	Outside	Warren	585	628	5,278	5,709
	Worcester	Outside	Webster	6,835	7,931	17,335	19,142
	Worcester	Outside	West Boylston	3,842	4,318	7,930	8,766
	Worcester	Outside	West Brookfield	851	859	3,800	4,096
	Worcester	Outside	Westborough	24,300	26,165	18,918	21,010

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
West	Worcester	Outside	Worcester	97,734	105,113	185,257	197,196
	Worcester	Outside	Ashland	5,634	5,718	17,519	20,892
	Worcester	Outside	Framingham	52,557	55,001	69,863	75,997
	Worcester	Outside	Holliston	4,840	6,236	13,266	12,870
	Worcester	Outside	Hopkinton	10,223	10,856	15,117	16,551
	Worcester	Outside	Natick	24,204	24,543	33,469	34,850
	Worcester	Outside	Marlborough	26321	27146	40,081	45,653
	Worcester	Outside	Sherborn	946	952	3,919	3,682
	Worcester	Outside	Southborough	7,453	8,174	9,909	11,082
	Worcester	Outside	Sterling	2,344	2,298	7,893	7,500
	SUBTOTALS	OUTSIDE		395,032	421,233	800,891	873,839
	SUBTOTALS	WEST		481,725	509,593	982,362	1,073,535
					6%		9%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
Boston	ALL LINES	INSIDE	Boston	600,371	646,946	645,570	743,967
					8%		15%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
Totals	COMMUTER RAILSHED		(Does not include Boston)	2,251,754	2,362,818	4,982,117	5,396,653
				5%		8%	
	Inside 128			605,613	646,666	1,275,396	1,437,552
					7%		13%
	Outside 128			1,646,141	1,716,152	3,706,721	3,959,101
					4%		7%
	North Side			1,051,963	1,100,629	2,266,358	2,478,724
	South Side			1,199,791	1,262,189	2,715,759	2,917,929
	TOTAL REGIONAL GROWTH - INCLUDES BOSTON			2,852,125	3,009,764	5,627,687	6,140,620
					6%		9%

Table C1: Boston Metro Employment and Population Projections

Source: Metropolitan Area Planning Council (MAPC) 2015 Projections; Long-Range Transportation Plan (LRTP), Charting Progress to 2040, Needs Assessment

Model Inputs

Inputs to the model include population by age; HHs by type (HHs by worker, by HH income, and by auto availability); and employment categories: basic, retail, and service.

The US Census is the source for population and HH data, while InfoUSA (a private data vendor) is the source for employment data. CTPS and the Metropolitan Area Planning Council (MAPC) purchased the data from InfoUSA in 2011, and spent a year analyzing and correlating the data before the agency staff were confident of their accuracy for use in the model. The census data do not require the same degree of verification as the InfoUSA data, but analysis was also required to check and prepare the census data for inputs to the model.

The transit information used in the model is from transit schedules published by the Massachusetts Bay Transportation Authority (MBTA). CTPS periodically updates the schedules in the model to reflect the most current schedule information. Typically, future-year No Build scenarios reflect base-year transit schedules. As shown in Table C2, the transit system simulation is based on four time periods: AM peak period (6:00 AM to 9:00 AM), midday (9:00 AM to 3:00 PM), PM peak period (3:00 PM to 6:00 PM), and early evening and night (6:00 PM to 6:00 AM).

Time Period	Highway Vehicle-Trips and Transit Person-Trips
AM peak period	6:00 AM to 9:00 AM
Midday	9:00 AM to 3:00 PM
PM peak period	3:00 PM to 6:00 PM
Early evening/night	6:00 PM to 6:00 AM

Table C2: Time Periods of Trip Assignments

Highway Data: Roadway information was taken from the 2012 MassDOT road inventory file. This information includes number of travel lanes per direction, segment length, posted travel speed, and functional classification for each road and highway.

The following cost data were used in the model:

- Mode-specific weighted transit fare (weighted based on the relative shares of pass holders, those paying full fares, and those with discount fares)
- Data on park-and-ride lot fees collected in 2012 for every known lot in the model area
- Information on applicable highway tolls collected in 2012 by individual toll facilities
- Auto operation costs calculated for the year 2012

MassDOT and the Boston Region MPO contributed funds to hire a consultant to conduct a statewide household travel survey during an 18-month period between June 2010 and November 2011, known as the 2011 Massachusetts Travel Survey (2011-MTS).

The 2011-MTS was used extensively to estimate, calibrate, and validate the CTPS model.

Trip Purposes

Daily HH activities are defined by trip purpose. The trip purposes that are represented in the CTPS model are home-based work (HBW) trips (work trips that have one end associated with the traveler's home), home-based personal business (HBPB) trips, home-based social-recreational (HBSR) trips, home-based school (HBSC) trips, home-based pick-up/drop-off (PUDO) trips, non-home-based work (NHBW) trips (trips that neither begin nor end at home, but begin or end at work), and non-home-based other (NHBO) trips (trips that neither begin nor end at home).

Truck, Taxi, Logan International Airport, and Through Trips

Other types of trips are also considered by the model, such as commercial vehicle trips (trucks), taxi trips, trips to and from Logan Airport, and through trips (trips that neither begin nor end in the modeled area, but pass through the modeled area).

Description of Future-Year Land-Use Scenario

MassDOT, through an extensive effort involving other state agencies, the UMass Donahue Institute, and the state's regional planning agencies, has developed a set of community forecasts for the

state. For the Boston region, MAPC allocated these community forecasts—or regional control totals—to TAZs.

MAPC allocated the MassDOT regional control totals to individual TAZs based on the Cube Land land-use allocation model, which is third-party software that forecasts land use by simulating the real estate market under different economic conditions. Cube Land forecasts the supply, location and rents by zone for different types of properties, estimating the location of households and non-residential activities for different demographic groups. The basis for Cube Land's land-use allocation model is a development tracking database (developed by MAPC), changes in parcel transportation accessibility (computed by CTPS), and community assessor and zoning maps. MAPC's application of Cube Land covers all 164 cities and towns in the MPO modeling area. (Note that this modeling area differs from the area covered by the MPO, which includes 101 cities and towns.)

CTPS Model – Four-Step Process

Trip Generation

Trip generation is the first step in the conventional four-step transportation forecasting process. It predicts the number of trips that are associated with HHs (trip productions) and the number of trips associated with employment sites (trip attractions). Every trip has two ends—a production end at the HH where the trip is initiated and an attraction end at the location where the trip culminates. This means that land use is characterized by two broad categories, residential and nonresidential. On the residential side, trip generation is thought of as a function of the social and economic attributes of HHs. On the nonresidential side, trip generation is thought of as a function of the number of jobs by activity.

Trip Distribution

The trip distribution model combines the estimated trip productions and trip attractions prepared by the trip generation model into tables showing both interregional and intraregional vehicle trips, which are then used as inputs into the highway assignment model (the fourth step of the modeling process, described below). Intraregional person-trip tables also are produced and are used as inputs for the mode choice model (the third step of the modeling process).

The trip distribution process used in the CTPS

model is a gravity model, which uses travel time and employment density to determine how *attractive* destinations are to travelers.

The gravity model takes the trips produced in one TAZ and distributes them to each of the other TAZs, based on the *attractiveness* of and distance to the other TAZs. The distance to possible destinations is the other factor used in the gravity model. The number of trips from an origin TAZ to all destination TAZs decreases as the distance between these destinations increases (this relationship is inversely proportional). The distance effect goes through a calibration process that leads to trip distribution in the model that is similar to that observed data.

Distance can be measured in several ways:

- Auto travel times between TAZs as the measurement of distance (this is the simplest method)
- A combination of auto travel time and cost as the measurement of distance
- Composite impedance, which is a combination of both transit and auto times, plus costs

The CTPS model uses composite impedance. This method involves calculating a share of the highway time and a share of the transit time. These time shares vary by origin-destination pair based on the number of auto trips and transit trips. The model must run through multiple iterations to balance the trip numbers, so that they match the trip productions and attractions, which are independently estimated in the trip generation step.

Mode Choice

Mode choice is the third step in the travel demand forecasting process. It is the process in which the trips from the distribution step are allocated to the available travel modes from the transportation network. Trip distribution establishes the volume of trips from one place to another, whereas mode choice estimates the mode that those travelers will use to make their trip.

CTPS used 2011 MTS data, information about travel impedances on the highway and transit networks, 2006-10 US Census data, and a variety of other data sources to develop a mode choice model by trip purpose. The mode choice model estimates what percentage of travelers will use each mode for four trip purposes:

- Home-based work (HBW) and work-related
- Home-based other (HBO)—including home-based shopping, personal business, social, recreation, and other miscellaneous purposes
- Home-based school (HBSC)—this trip purpose was further divided into HBSC1 (ages 0 to 13), HBSC2 (ages 14 to 18), and HBSC3 (ages 19 and older)
- Non-home based (NHB)—including non-home-based work and non-home-based other trips

The mode choice model is applied, by trip purpose, to the distributed trip tables that result from the trip distribution model, and splits the trip purposes between the following modes:

- Auto: drive alone (DA)
- Auto: two occupants (SR2)
- Auto: three or more occupants (SR3+; for HBW only)
- Transit: drive access to commuter rail (DAT_CR)
- Transit: drive access to rapid transit (DAT_RT)
- Transit: drive access to local bus (DAT_LB)
- Transit: drive access to boat/ferry (DAT_B/F; not for HBSC)
- Walk to transit (Boat, CR, RT, and bus)
- Nonmotorized: walk, bike

The number of trips in the 2011–MTS data by trip purpose, as well as the characteristics of the transportation system in the modeling area, determined the modes and trip purposes considered in the mode choice model. The transportation system characteristics can be thought of as a kind of level-of-service metric that aggregates various facility characteristics into one metric.

Transit Path-Building

The following topics have been discussed: how many trips will be made; where these trips will go; and what mode they will take. This section covers what route within that mode will be taken.

For transit trips, the path selected is based on the lowest generalized cost. This means that all components of the transit trip (access time, egress time, waiting time, in-vehicle time, fare, and transfer cost and time) are converted to one variable, which is cost. The transit path with the lowest cost is chosen.

Wait-time estimations in the model vary depending on the frequency of a particular service but are capped at ten minutes' waiting time. Transfer time includes the time it takes to walk between two stops. The model caps the allowed number of transfers at six.

Highway Path-Building

For highway trips, the path is based on the minimum congested travel time path. The travel time is calculated based on the traffic volumes, which result from the highway assignment.

Trip Assignment

Trip assignment is the fourth step in the travel demand forecasting process. Trip assignment models are used to estimate the traffic and passenger flows on a transportation network. Trip assignment is the most time-consuming step—as well as one of the most data-intensive steps—of the four-step modeling process. The process is somewhat different for highway travel than for transit travel.

Highway Assignment Overview

The highway assignment model predicts the flows on the network, generates estimates of travel times, and produces attributes that are the basis for traffic volume and capacity analyses. This model is also used to generate the estimates of network performance that are used in the mode choice and trip distribution models.

The CTPS roadway/highway assignment procedure assigns highway trips to the highway network so that each user of the highway network chooses the route that he or she perceives to be the best. The assignment procedure is performed for each time period.

For more realistic assignment results, the assignment procedure recognizes that different groups of highway users value network attributes

(for example, travel time) differently. The highway users are represented by drive-alone auto trips, shared-ride auto trips, and truck trips.

The generalized cost is computed as the combination of the travel time and a toll equivalent time. Toll costs affect the assignment and are stored on the network. The generalized cost is converted to an equivalent time by applying the value time to the toll. The value of time for autos is \$0.20 per minute (\$12.00 per hour). This value is based on the average hourly rate for the region in 2010 dollars. Trucks have a significantly higher value of time. For small single-unit trucks, the value of time is \$0.75 per minute. For large single-unit trucks and combination vehicles, the value of time is \$1.00 per minute.

The assignment procedure uses the user equilibrium method—an iterative process which assigns trips to a series of routes until a level of travel time parity is achieved across the network. Travel time is a function of the assigned traffic volume and the road capacity. Road capacity is estimated based on the roadway attributes, such as the number of lanes. For each iteration of assignment, the highway trips between zone pairs are assigned to routes with the minimum cost and travel time is calculated after trip assignment. The iterative process stops when changing user's paths will not achieve a faster route.

Transit Assignment Overview

To perform a transit assignment, the following inputs are needed:

- Transit route system
- Fare structure
- Demand for passenger trips between different origins and destinations
- After the demand matrices of drive access trips (DAT) and walk access trips (WAT) are forecast, the trips are assigned to the transit network and combined by time period. The congestion of passengers at stops and terminals does not influence travel times or behavior in the model.

Finally, summaries of transit boardings by submode (for example, buses, rapid transit, ferry, commuter rail) and time of day are produced, along with boardings and alightings at rapid transit and commuter rail stations, with subtotals by line. For buses, summaries of boardings are produced that are classified by the MBTA bus route number and time of day.

Other Model Outputs

Environmental Justice

When required, CTPS performs an environmental justice (EJ) analysis in the model. The EJ analysis examines the benefits and burdens of the project on EJ communities in the study area.

The EJ analysis is performed at the level of the TAZ. TAZs are identified as being EJ TAZs if their populations meet certain thresholds with regard to income, race, or in some cases, English language proficiency. The thresholds are based on regional or statewide averages.

The EJ analysis typically measures the change in accessibility to employment for a given alternative. That change is measured for trips within a particular area, or travel shed. The travel shed that is established depends on the particulars of the study and the alternatives being examined.

For example, if the study focuses on a commuter rail extension that would involve a 90-minute train ride to Boston, the travel shed would be defined as the area around the train route being analyzed.

Air Quality

When required, CTPS also performs an air quality mobile source emissions analysis. CTPS uses the travel demand model in conjunction with MOVES 2014a—the US Environmental Protection Agency’s (EPA) Motor Vehicle Emission Simulator—to estimate mobile source emissions from all modes of transportation for the different alternatives studied. Commuter rail emissions are estimated based on guidance from the EPA.

MOVES 2014a uses vehicle-miles traveled as well as vehicle speed, in combination with fleet emissions rates, to estimate mobile source emissions. Emissions factors for motor vehicles are specific to each vehicle model year, pollutant type, temperature, and travel speed. MOVES 2014a utilizes a wide range of input parameters, including inspection and maintenance program information, and other data such as hot/cold start mix, emission failure rates, vehicle fleet mix, and fleet age distribution.

The EPA guidance employs a similar methodology to estimate emissions for locomotives. Track miles are considered along with specific emission factors to develop air quality estimates associated with the trains. CTPS estimates train emissions for vehicle fleets of different ages, using a methodology employed by the EPA.

D. Fire and Life Safety

This Appendix provides further detail on Fire and Life Safety requirements and design, as they pertain to the NSRL project.

Means of Egress: Stations

The National Fire Protection Association (NFPA) publishes consensus codes and standards for minimization of fire and other risks, and the NFPA 130 Standard specifies fire protection and life safety requirements for fixed guideway transit and passenger rail. Per NFPA 130, the means of egress system at each station must be designed based on the station's passenger load. This occupant load is calculated based on projected peak period train loads at the station in question, and is the sum (assuming simultaneous train movements on all tracks in normal traffic directions) of all passengers entering the station and outgoing passengers awaiting trains on the platforms.

NFPA 130 takes a performance-based approach to egress system design, requiring that evacuation time from the platform be less than four minutes, and that the total evacuation time from the most remote point of a platform to a Point of Safety be less than six minutes. Evacuation time is based on the design passenger load, means of egress components used, their maximum capacity and travel speed as prescribed by NFPA 130, and travel distances. The predicted passenger load at each station informs the number and capacity of the exits required for the station.

Since ridership numbers are fluid and can change significantly over the useful life of the station, for maximum flexibility each station should have at least four exits (the minimum requirement under the

Ninth Edition of the Massachusetts Building Code for a space serving more than 1,000 occupants). NFPA 130 limits the travel distance between the platform and a point where an egress route leaves the platform to 325 feet, and limits the common path of travel from the platform ends to 82 feet or one car length (whichever is greater).

Since NFPA 130 allows stairs, ramps, escalators, elevators, and doorways to be part of the means of egress system, and since these components also serve as points of ingress to the station, the recommended means of egress strategy (again, with a minimum of four exits/entrances) complies with code for a space with a large occupant load (over 1,000 people), and can provide convenient access points to and from the station for the riders and the general public.

Furthermore, the Standard specifies the following requirements:

- Escalators may not account for more than 50% of the required means of egress capacity at any one level except where the escalators can be brought to a stop remotely
- Each station level is also served by at least one stairwell, with at least one enclosed exit stairwell or exit passageway providing continuous access between platforms and the public way.
- Elevators used as a means of egress must not account for more than 50% of required egress capacity.

- Elevators used as a means of egress must be accessible via holding areas that are smoketight and fire-rated for a minimum of one hour or lobbies that are served by a stairwell. Elevator shafts must be fire-rated for at least two hours.

In addition to meeting the specific NFPA 130 component requirements shown in Table D15, the means of egress from stations must be provided with emergency lighting.

An alternative would be to base the egress system and features on a performance-based analysis (performance approach). A performance approach is an engineered process that focuses on meeting goals and objectives rather than prescriptive requirements. Based upon the unique nature of these deep stations, a performance-based egress analysis would be appropriate and would be recommended as part of future assessments.

Means of Egress Component	Minimum Clear Width [in]	Maximum Means of Egress Capacity [person/in-min]	Maximum Travel Speed [ft/min]
Platforms Corridors Ramps	44	2.08	124
Concourses Areas of lower pedestrian density	44	2.08	200
Stairs Escalators	44	1.41	48 (vertical)
Doors Gates[single leaf]	n/a	60 person per minute for each component	n/a
Doors Gates [bi-parting multi-leaf]	n/a	2.08	n/a
Fare barriers	21	50 person per minute for each component	n/a

Table D1: NFPA 130 Means of Egress Component Requirements

Means of Egress: Tunnels

Evacuation from a vehicle within the trainway tunnel must allow the riders to proceed to the nearest station or another Point of Safety. Within the tunnel, exits must be located within 2,500ft of one another. Exit stairs must be constructed along the tunnels. This configuration can be cost-prohibitive, depending on proposed tunnel depth and the availability of open land on the surface.

However, NFPA 130 also allows cross-passageways in lieu of emergency exit stairways when tunnels are divided by fire separation that is rated for a minimum of two hours or where tunnels are in twin bores. The cross-passageways must be within 800ft of one another and of station boundaries or tunnel portals, and must have minimum dimensions of 44in clear width and 7ft clear height. The intent is for the cross-passageways to allow riders from one trainway or bore to enter into another trainway or bore, thereby separated from the hazard and able to continue on the evacuation route. To facilitate egress, ventilation for the incident trainway must be designed to control smoke spread in the vicinity of the passengers.

Fire Protection Features: Stations

Each station must be provided with an accessible fire command center. The fire command center is the main area displaying the status of the detection; containing alarm communications, control systems, and other emergency systems; and from where the systems can be manually controlled.

Automatic sprinklers are required in areas of a station used for concessions, storage, and trash collection, and in other similar spaces with combustible loadings (except tunnels). The sprinkler system is provided with a water flow alarm and supervisory signal service, and the system design and installation are required to comply with NFPA 13, the standard for sprinkler system installation. The City of Boston may require additional areas, such as back-of-house, lobbies, MEP rooms, or concourses, to be protected by automatic sprinkler systems.

Class I standpipes in accordance with NFPA 14, the standard for standpipe and hose systems, are required at each station. The standpipe system must be enclosed in fire construction unless the system is cross-connected or fed from two locations and the isolation valves are installed 800ft apart or less. The system is also required to be 'wet type' (standpipes with a continuous water supply) except where approved by the authority with jurisdiction, and where the system is designed so that water is delivered to all hose connections within 10 minutes and combination air relief-vacuum valves are installed at each high point of the system.

Each station is required to:

- Be protected by a fire alarm system designed and installed per NFPA 72. The fire alarm system must be provided with a fire alarm annunciator panel at an approved location accessible to emergency response personnel.
- Incorporate automatic fire detection in all unsprinklered ancillary spaces by temperature and rate-of-rise heat detectors or smoke detectors that achieve listed standards. Activation of initiating devices must be announced at the Panels must announce activation of devices by audible alarm and visually display the location of the actuated device.
- Include separate alarm zones to monitor water flow and supervise main control valves for the automatic sprinkler. All indicator signals for fire alarms, smoke detection, valve switches, and water flow must be simultaneously transmitted to the local fire station and to the operations control center for the rail system.
- Provide an emergency communications system at each station that is in compliance with Chapter 10 of NFPA 130 .

NFPA 130 requires that the authority with jurisdiction determines the number, size, type, and location of any portable fire extinguishers to be installed in a train station.

Emergency power, in accordance with Article 700 of NFPA 70 and Chapter 4 of NFPA 100, is required for each station. The emergency power system is sized to selective load pickup and load shedding of the following systems:

- Emergency lighting
- Protective signaling
- Emergency communications
- Fire command center
- Elevators providing required egress capacity

Fire Protection Features: Tunnels

An emergency communications system in compliance with Chapter 10 of NFPA 130 is required within the tunnels.

At traction power substations and signal bungalows, heat and smoke detectors connected to the operations control center are required per NFPA 130. An automatic sprinkler system is not required within the tunnels per NFPA 130.

Class I standpipes are required to be installed within the tunnels. In addition to the requirements for standpipes for station structures, an approved water supply must provide the system demand for a minimum of one hour. Approved water supplies include a municipal or privately owned waterworks system, automatic or manually controlled fire pumps connected to a water source, or pressure-type or gravity-type storage tanks per NFPA 22. A fire department connection is required for the system, and a fire department access road must reach within 100ft of the fire department connections. The authority with jurisdiction determines the number, size, type, and location of any portable fire extinguishers to be installed within the tunnels.

Emergency power is required for the enclosed tunnels. The emergency power system will connect to the following systems within the trainway tunnel:

- Emergency lighting
- Protective signaling
- Emergency communications
- Fire command center

Ventilation

NFPA 130 requires a tunnel ventilation system, which performs a number of functions. The primary function is to ventilate any smoke produced during a fire event, to allow a clear path for evacuating passengers from any trains either in the tunnels between stations or in the stations themselves.

The tunnels will be cleared using a fan plant at either end of a tunnel segment, and these operate using the 'push-pull' principle (the fan plant at one end of the affected tunnel segment will be operated in supply mode, while the plant at the other end will operate in exhaust mode, as shown in Figure D3). A critical velocity is attained to force smoke in one direction while passengers exit in the opposite direction.

In the event of a train fire within a station, the fan plants at that station operate in exhaust mode. An over-track exhaust duct clears smoke from all areas of the platform outside the immediately affected area to meet visibility, temperature and carbon monoxide concentration tenability criteria at 6ft (1.8 meters) above platform level.

A fan plant is provided at both ends of each station to meet these ventilation needs. A series of dampers and ducts allows the same fan plant to ventilate either the station or the adjacent tunnel. These fan plants are connected by large shafts to a surface structure (vent building) to discharge or intake air.

A piston relief system, as shown in Figure D4, keeps

air velocities on the platform within acceptable limits and prevents heat buildup within the tunnels and stations. This directs the air carried along with the trains on an alternate path, rather than allowing the air to find its way to the surface through station entrances. To minimize costs, piston relief shafts are combined with fan shafts to the greatest extent possible.

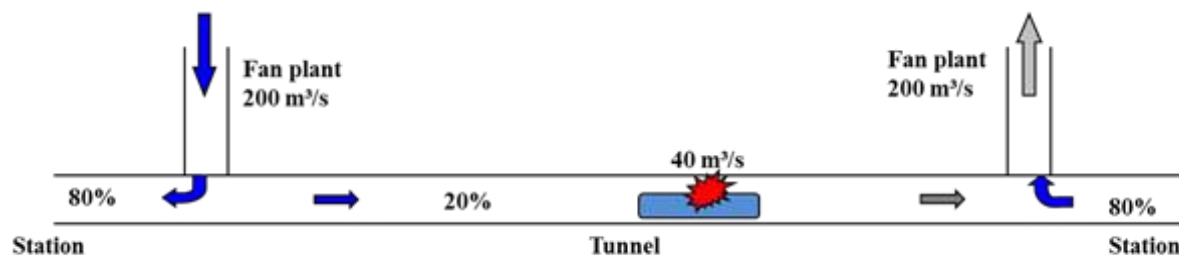


Figure D1: Tunnel Ventilation

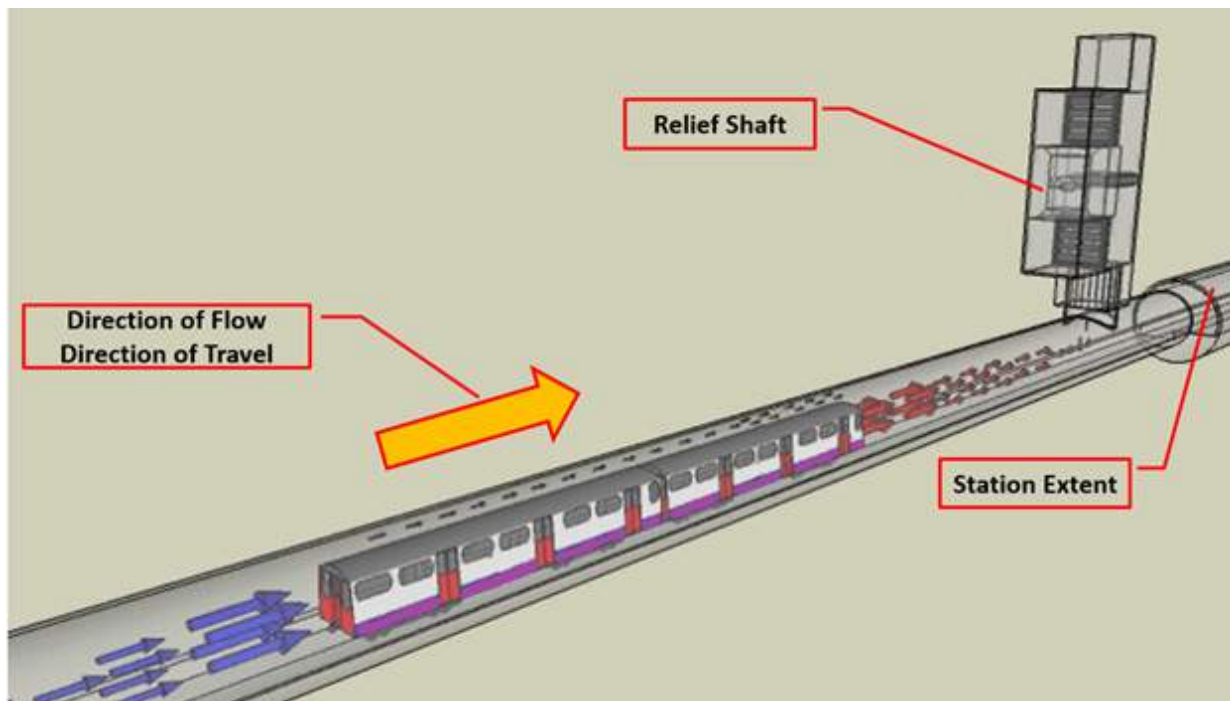


Figure D2: Piston Effects in a Train Tunnel

If a train is stopped between stations in the tunnel and the temperature within the tunnel rises above acceptable limits, the tunnel vent plants at each end operate in push-pull mode. This provides cooling air to prevent the train's air conditioning units from overheating and shutting off. While all locomotives in revenue service or routine operation in the NSRL tunnels are assumed to be electric, on occasions that diesel equipment uses the tunnels, the fans can also be used to purge diesel exhaust.

Fan plants can be located in a number of configurations, depending on various site conditions. If real-estate is available, the fan plants can be located above-grade, otherwise the generally more expensive option of providing space within the station box applies, as shown in Figure D5. The fans themselves can be mounted horizontally or vertically to suit the available space. A typical horizontal fan plant requires an approximate 75ft by 50ft space. In addition, there are associated electrical spaces to house the starters, transformers and controls for the fans.

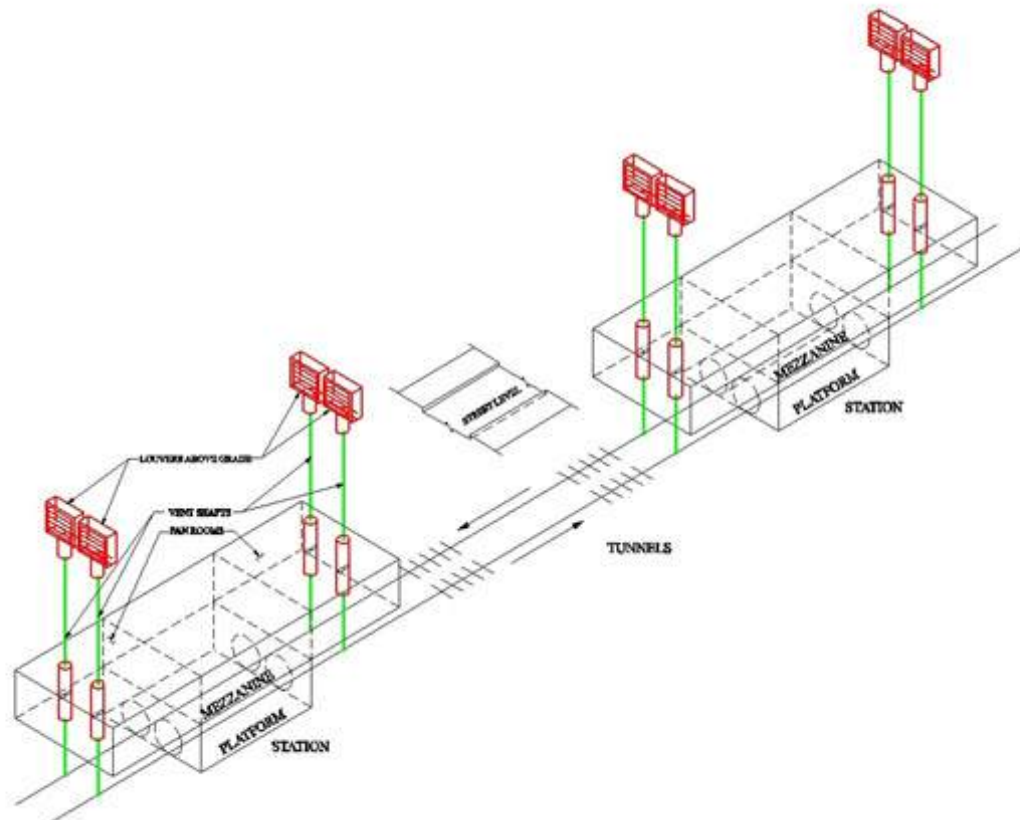


Figure D3: Integrate Tunnel-Station Ventilation Fan Plant

NFPA 130 requires two independent electrical power sources for each fan system for redundancy. Spare fan capacity is provided such that the required performance can be maintained with the most critical fan out of service. The fans are reversible axial type with associated sound attenuators. Dampers are provided to allow fans to be taken out of service as well as to allow the system to operate in the various modes. A Supervisory Control and Data Acquisition (SCADA) system is provided to control the fans, which are interfaced with the rail control center.

In order to facilitate effective ventilation for the tunnel sections between the portals and the adjacent stations, a fan plant or a set of jet fans is required. Similar to fans inside a vent building, jet fans can provide makeup or exhaust air into the tunnel to control the smoke spread. Jet fans are recommended for both the North and South portals due to lower costs than a vent building. However, at the South portal location, smoke exhausted by jet fans at the tunnel opening may pose an environmental and pollution issue due to the high building/occupant density in the adjacent area. Thus, at the South portal location, a vent building may be necessary.

The following maps show possible locations for the vent buildings, based on adjacency to stations, the availability of land, and the potential costs related to acquisition.



Figure D4: Possible Vent Building Locations at North / State/Haymarket Station

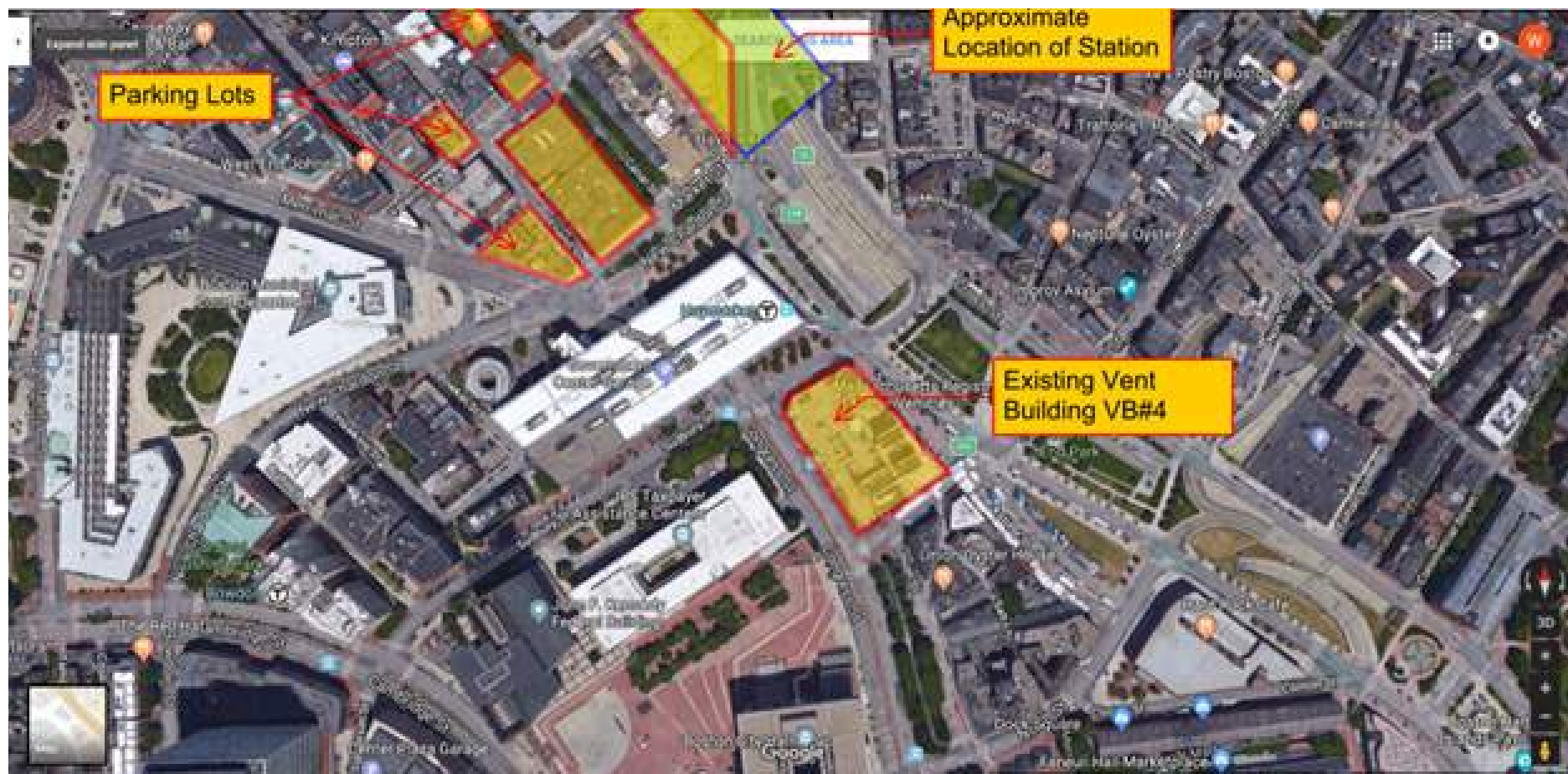


Figure D5: Possible Vent Building Locations at North / State/Haymarket Station (Cont.)

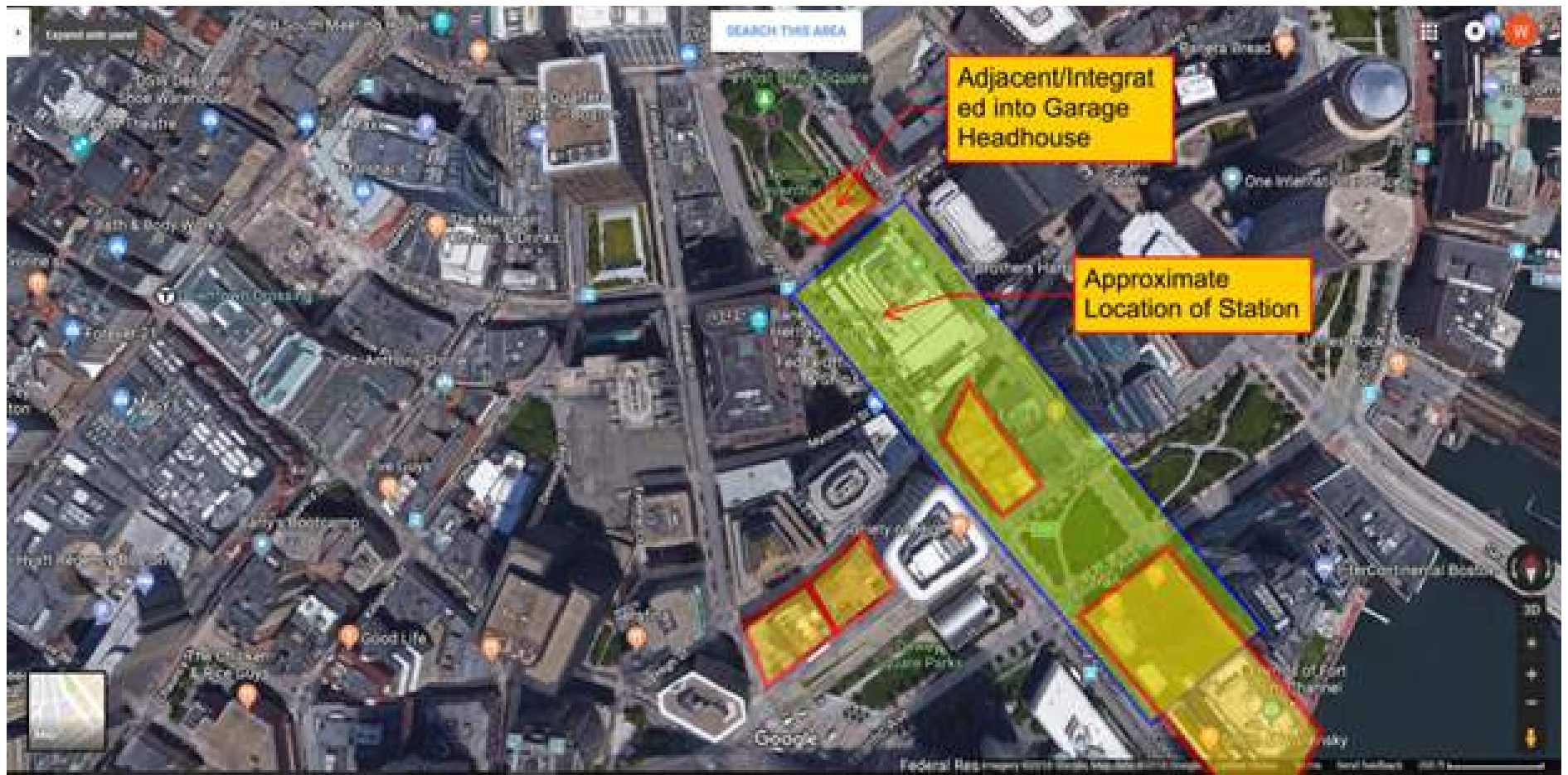


Figure D6: Possible Vent Building Locations at South Station Pearl/Congress Alignment



Figure D7: Possible Vent Building Locations at South Station Central Artery Two-Track Alignment



Figure D8: Possible Vent Building Locations at South Station Central Artery Two-Track Alignment (Cont.)



Figure D9: Possible Vent Building Locations at South Station South/Congress Alignment



Figure D10: Possible Vent Building Locations at North Portal



Figure D11: Possible Vent Building Locations at South Portal

E. Cost Estimate

Estimate Format and Work Breakdown Structure

The Work Breakdown Structure (WBS) for the NSRL project has been laid out as follows:

- South Station Expansion (No NSRL) alternative
 - **Dorchester Avenue improvements:** divided into pavement works, landscaping, appurtenances, traffic management, drainage, utilities, etc.
 - **South Station headhouse:** divided into its major components, such as foundation, substructure, superstructure, mechanical, electrical and plumbing (MEP), and furnishings
 - **South Station Expansion:** divided into civil works (drainage, noise barriers) and track work
 - **Readville & Widett Circle layover facilities:** divided into pavement works, drainage and other civil components, track work, and buildings
- Tunnel alternatives (all alignments follow the same WBS)
 - **Tunneling works:** including tunnel boring machine (TBM), mined tunnels, tunnel systems, and fit-out
 - **Station work:** including excavation, access shafts, station fit-out, systems, and conveying equipment
 - **Trackwork:** including civil works for at-grade track, track work per mile, systems (signaling and electrification)
 - **Portal works:** including civil works, track work, and electrification
 - **Allowances:** including underpinning and utility relocations
- Upstream/downstream improvements (all alternatives follow the same WBS)
 - **Additional layover facilities:** pavement works, drainage and other civil components, track work, and buildings (in NSRL alternatives only)
 - **Fitchburg Line:** including additional platform capacity and double-track work
 - **Old Colony Line:** including double-tracking
 - **Newbury/Rockport Lines:** including double-tracking
 - **Needham Line:** including double-tracking
 - **Providence/Stoughton Line:** including additional platform capacity
 - **Worcester Line:** including additional platform capacity and resignaling works
 - **Haverhill Line:** including double-tracking
 - **Franklin Line:** including double-tracking and additional turnback crossover
 - **Fairmount Line:** including double-tracking and electrification (priced separately)
 - **Lowell Line:** electrification (priced separately)

Table E1 summarizes the main scope differences between this Feasibility Reassessment and the 2003 study.

To obtain the total project costs, a cost estimating algorithm was applied to incorporate all relevant costs, such as indirect costs, overhead and profit, soft costs, contingencies, and escalation. Figure E-1 summarizes the estimating algorithm that applies to all performed estimates.

The accuracy range based on AACEi cost classification matrix was then applied to the total project cost.

	2003 Study	2018 Study
Tunneling	Diameter of 41.5ft No detail on launch pits	Diameter of 41.5ft Larger diameter requires deeper tunnels for the benefit of complete tunnel containment in bedrock Cost includes launch pit of one TBM for the Central Artery 2-track alternative, and launch pit for two TBMs for the Central Artery 4-Track alternative
Portals	Includes level junctions	Includes level junctions and grade separation for both alignment alternatives (Central Artery 2-Track and 4-Track)
Vertical Alignment	Maximum grade of 3%	Maximum grade of 2.75%
Horizontal Alignment	Alignment goes under the Federal Reserve property at 600 Atlantic Avenue	Alignments avoid Federal Reserve property at 600 Atlantic Avenue
Back Bay Station	Unaffected	Need to split and lower an entire platform to fit underneath the Orange Line and to maintain a connection to the Worcester Line with the NSRL tunnel
Existing Buildings	No detail provided	Deeper knowledge of existing foundations and obstacles throughout the alignment, which has resulted in allowances made for underpinning works

Table E1: High-Level Scope Comparison Between Current Feasibility Reassessment and 2003 Study

Estimate Methodology

Cost is used for the comparison of similar alternatives. The cost estimates were generated to meet the level of accuracy in accordance with the current design.

The estimate was developed by establishing the full scope for all alternatives, assigning appropriate unit costs for each line item, and applying the relevant markups to arrive at a total project cost in the desired year of analysis.

Standard Estimating Algorithm			
Design Build Entity	TDC	Total Direct Costs	TDC
	TIC	Total Indirect Costs	TIC
	TC	Total Cost	TDC+TIC=TC
	OH&P	Overhead & Profit	OH&P
	STP	Sub Total Price	OH&P+TC = STP
	C	Contractor's Contingency	C
	TP	Total Price	STP+C=TP
	PE FD	Preliminary Engineering / Final Design	PE FD
	T DB	Total Design Build Price	TP+PE FD
Owner	SC	Soft Costs	SC
	ST SC	Sub Total with Soft Costs	T DB + SC = ST SC
	RC	Risk Contingency	RC
	TPC	Total Project Cost	ST SC + RC = TPC
	E	Escalation	E
	TPCT	Total Project Cost at a Specific Point in Time in the Future	TPC + E = TPCT

Figure E1: Estimating Algorithm

Quantity Development

For each component or specific element of work, a measurement of the quantities needed for completion (or a “quantity takeoff”) was performed with the available information, considering that the level of engineering is below 5%. Based on alignment lengths, the following scope items were calculated:

- Tunnel lengths (by type of tunneling method: TBM bore, mined)
- Tunnel excavation volumes based on tunnel cross sections
- Tunnel fit-out concrete volumes based on tunnel cross sections
- Trackwork length

Based on 3-D models created in-house, the following quantities were calculated:

- Station excavation volumes (cut-and-cover or mined)
- Station access shafts
- Station platform and concourse areas
- Underpinning needs

Table E2 summarizes the main scope components for the tunnel alternatives and their key driver quantities.

	Central Artery 2-Track	South/Congress	Pearl/ Congress	Central Artery 4-Track
TBM launch pit (area in ft²)	86,112	131,072	37,845	172,225
TBM launch pit (volume in cubic yards [cy])	264,716	397,682	225,824	529,432
TBM excavation length (route miles)	2.22	2.04	2.15	2.65
Mined excavation length (route miles)	0.91	0.99	1.16	1.23
Portal works – retained cut (route miles)	2.27	2.46	2.46	2.74
Total Alignment Lengths (miles)	5.40	5.49	5.77	6.62
South Station Exc. Volume (cy)	287,141	72,349	279,414	563,152
Central Station Exc. Volume (cy)	N /A	N /A	N /A	314,456
North Station (or Haymarket) Exc. Volume (cy)	161,517	72,349	279,414	314,456
Total Station Excavation Volume (cy)	448,658	144,698	558,828	1,192,064

Table E2: Main Scope Component Quantification

Table E3 summarizes the scope added for the upstream/downstream improvements.

Allowances and assumptions were made in order to include items that are not quantifiable from the current level of design.

Quantity takeoffs were performed on the 30% Preliminary Engineering drawings provided by the South Station Expansion team for the South Station Expansion (No NSRL) alternative, which encompasses Dorchester Avenue improvements, the South Station headhouse and trackwork, and new layover facilities at Readville and Widett Circle.

	South Station Expansion (No NSRL)	Central Artery 2-Track	South/Congress	Pearl/Congress	Central Artery 4-Track
Additional Platforms (Each)	4	3	3	3	4
Double-Track Length (track miles)	8.2	9.6	9.6	9.6	9.6
Additional Turnback Crossovers (Each)	2	3	3	3	3
Resignaling of Critical Points (miles)	30	30	30	30	30

Table E3: Scope of Upstream/Downstream Improvements

Benchmarks and Unit Price Buildup

A combination of unit cost approaches was used to determine the total cost for all scope items. For tunneling works, where tunnel cross sections and construction methodology are the only parameter, benchmarks from historical databases were used based on excavation and lining costs per mile of tunnel. For all other scope items, unit rates were derived using the unit method of costing, which uses single-functional unit rates based on historical data from previous and similar construction projects. Assumptions were made to assess the quantities and costs of certain scope items (e.g., sheet pile types for the cofferdams and retaining wall types for the portals).

Figures E2 and E3 summarize the benchmarks for TBM bores and sequential-excavation-method mined shafts/tunnels. Each graph contains the NSRL estimate’s data point, shown as a dashed line. Tables E-4 to E-6 provide supporting detail for the information contained in the graphs.

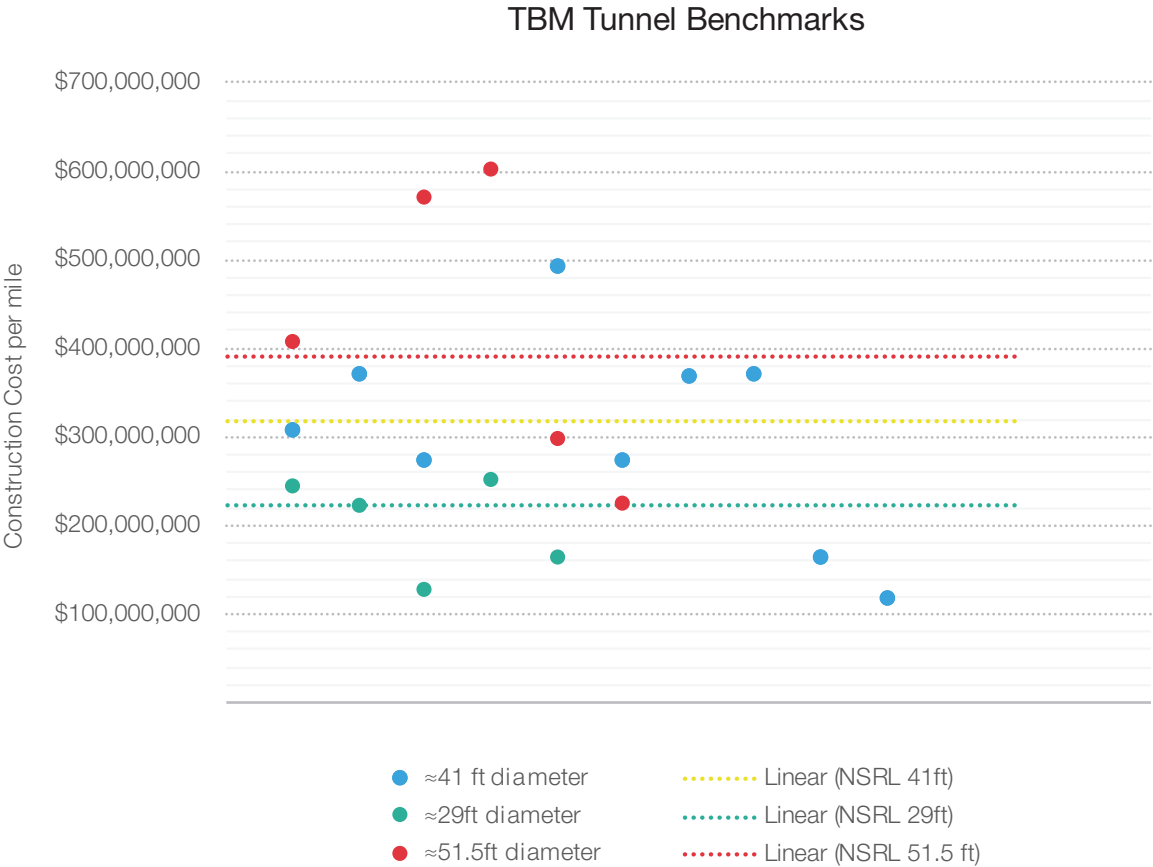


Figure E2: TBM Tunnel Construction Cost Benchmarks by Tunnel Diameter Compared to NSRL Costs (2018 USD)

Project	Location	Diameter	Year	Normalized cost per mile
California High Speed Rail	Los Angeles	40ft	2009	306,976,500
Wesertunnel	Germany	38ft	2001	370,036,200
I-710 (C3)	Los Angeles	42ft	2017	273,125,000
Airport Link Brisbane	Brisbane, Australia	41ft	2012	491,121,000
A86W	Paris, France	38ft	2010	368,828,500
Dublin Port Tunnel	Dublin	38ft	2006	162,703,900
Westerschelde	Netherlands	37ft	2002	117,958,300
California High Speed Rail	Los Angeles	30ft	2009	242,725,600
Crossrail - C300 Western Running Tunnels	UK	20ft	2010	222,361,200
Crossrail - C305 Eastern Running Tunnels	UK	20ft	2010	127,064,900
Beacon Hill Tunnel	Seattle	21ft	2009	250,447,000
Pannerdenschkanaal	Netherlands	32ft	2003	163,356,100
California High Speed Rail	Los Angeles	50ft	2009	406,922,300
Groene Hart Tunnel	Leiderdorp, Netherlands	48ft	2006	568,792,300
4th tube of the Elbe	Hamburg, Germany	47ft	2002	601,830,300
I-710 (A3)	Los Angeles	50ft	2017	297,767,900
M-30	Madrid, Spain	50ft	2008	223,174,500

Table E4: Data points of Figure E-2 TBM Tunnel Construction Cost Benchmarks, with normalized costs to 2018 USD, Boston Location Factor

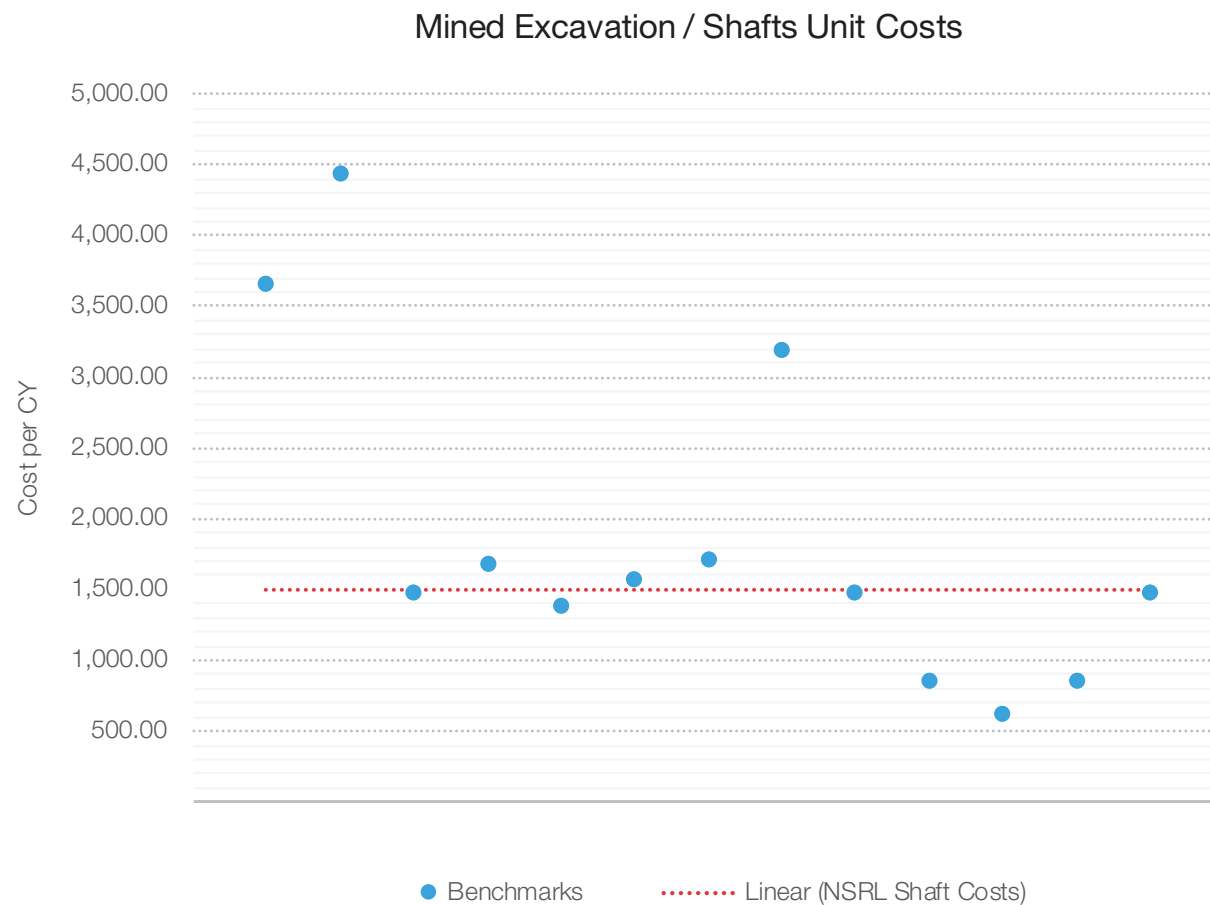


Figure E3: Mined Excavation / Shaft Excavation Data Points (2018 USD)

These figures correspond to benchmarks with similar tunnel parameters (diameters, constraints) as the ones analyzed for the NSRL project. To corroborate the validity of these benchmarks, tunneling expert input was obtained. All analyzed benchmarks have been normalized to reflect the location of the project (Boston, Massachusetts) and the year of analysis (2018). Table E6 summarizes the most important tunnel parameters used to assess the benchmarks.

Project	Location	Year	Normalized cost per CY
California High Speed Rail	Los Angeles	2009	3,667
California High Speed Rail	Los Angeles	2009	4,442
California High Speed Rail	Los Angeles	2009	1,482
California High Speed Rail	Los Angeles	2009	1,685
California High Speed Rail	Los Angeles	2009	1,394
California High Speed Rail	Los Angeles	2009	1,580
CTRL (220), 2 Shafts	UK	2001	1,712
CTRL (240), 2 Shafts	UK	2001	3,195
Beckton Overflow (Drive) Shaft	UK	2009	1,483
Beckton Connection Shaft	UK	2009	856
Beckton Pump Station Shaft	UK	2009	628
Abbey Mills Station F Shaft	UK	2009	856
Abbey Mills Station A Shaft	UK	2009	1,483

Table E5: Data points of Figure E-3 Mined Excavation / Shaft Excavation, with normalized costs to 2018 USD, Boston Location Factor

Geometric	Tunnel diameter	Tunnel length
Constructive	Type of tunnel excavation	
Economic	Location of project	Year of construction

Table E6: Tunneling Parameters Analyzed in Benchmarks

Figure E4 shows the impact of tunnel diameter in the TBM construction costs per mile. Table E7 contains the supporting detail.

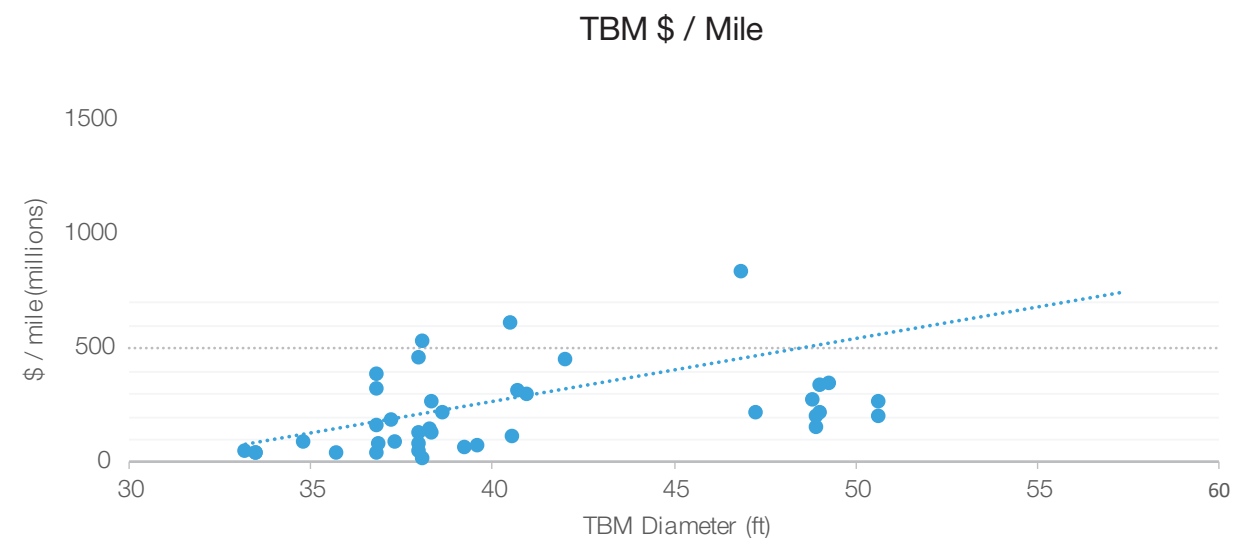


Figure E4: TBM Tunnel Construction Cost Benchmarks by Tunnel Diameter (2018 USD)

TBM Tunnel	Location	Year	Diameter (ft)	\$ / mile
Alaskan Way	USA	2012	57	989
Qianjiang Subaqueous Tunnel	China	2010	51	189
Yangtze River Tunnel	China	2005	51	253
M-30 Orbital Motorway South Bypass	Spain	2005	49	350
Nanjing River Crossing 1st	China	2005	49	203
Nanjing River Crossing 2nd	China	2010	49	322
Hong Mei Road South	China	2010	49	194
Groene Hart Tunnel	Netherlands	2002	49	167
Jungong Road - Shangzhong Road	China	2004	49	255
Niagara	Canada	2006	47	230
Bund Tunnel	China	2007	47	782
Lefortovo	Russia	2002	47	1116
Port of Miami	USA	2011	42	497
Airport Link Brisbane	Australia	2008	41	328
Legacy Way	Australia	2012	41	338
Oenzberg Tunnel	Switzerland	2000	41	134
North South Bypass	Australia	2006	40	658
Barcelona Metro: Drive 3	Spain	2003	40	75
Barcelona Metro: Drive 1	Spain	2003	39	71
Dublin Port Tunnel: Whitehall to Fairview Park Drive 1	Ireland	2002	39	236
Qingchung Road Subaqueous Tunnel	China	2006	38	127

TBM Tunnel	Location	Year	Diameter (ft)	\$ / mile
Herren Tunnel: South Drive	Germany	2002	38	286
Weser Tunnel: Southern Drive	Germany	1998	38	154
Paris, A86 - East Drive	France	2000	38	18
Paris, A86 - West	France	1999	38	564
Chengjiang River Road West	China	2010	38	51
Xiangyin Road (South)	China	2005	38	81
Dapu Road 2nd Tunnel	China	2006	38	429
Xiangyin Road Tunnel	China	2003	38	120
Wuhan Yangze River Crossing	China	2004	37	90
Westerschelde	Netherlands	2003	37	201
Weinberg Tunnel	Switzerland	2010	37	95
Yan'an Road East Tunnel	China	1994	37	362
Fuxing Road Tunnel	China	2001	37	153
Dalian Road Tunnel	China	2001	37	303
Katzenberg Tunnel	Germany	2005	37	50
Finne Tunnel	Germany	2012	36	51
Hallandsas	Sweden	2004	35	95
Abdalajis Rail Tunnel: East Tube	Spain	2003	33	44
Abdalajis Rail Tunnel: West Tube	Spain	2003	33	46
New Kaiser Wilhelm Tunnel	Germany	2009	33	56

Table E7: Data points of Figure E-4, normalized to 2018 USD

When quantities were not readily obtainable due to the level of engineering available, allowances were made to incorporate the potential cost for specific scope items (e.g., utility relocations, detailed underpinning scope, and roadway reconstruction).

Based on the total costs of the NSRL project, excluding escalation, Tables E8 and E9 and Figure E5 were created as part of a peer matrix produced for this Feasibility Reassessment. They are based on total cost and scope of similar projects, reflecting a total cost per alignment mile. The diameters of all benchmarked projects in the peer matrix are different than the diameters of the tunnels in the NSRL project.

Average Cost per Route Mile (Benchmarks USA) (2018 USD, Boston Location Factor)	\$1,343,370,129
Average Cost per Route Mile (Benchmarks, Global) (2018 USD, Boston Location Factor)	\$1,147,138,767

Table E8: Average of Global and USA benchmarks (2018 USD)

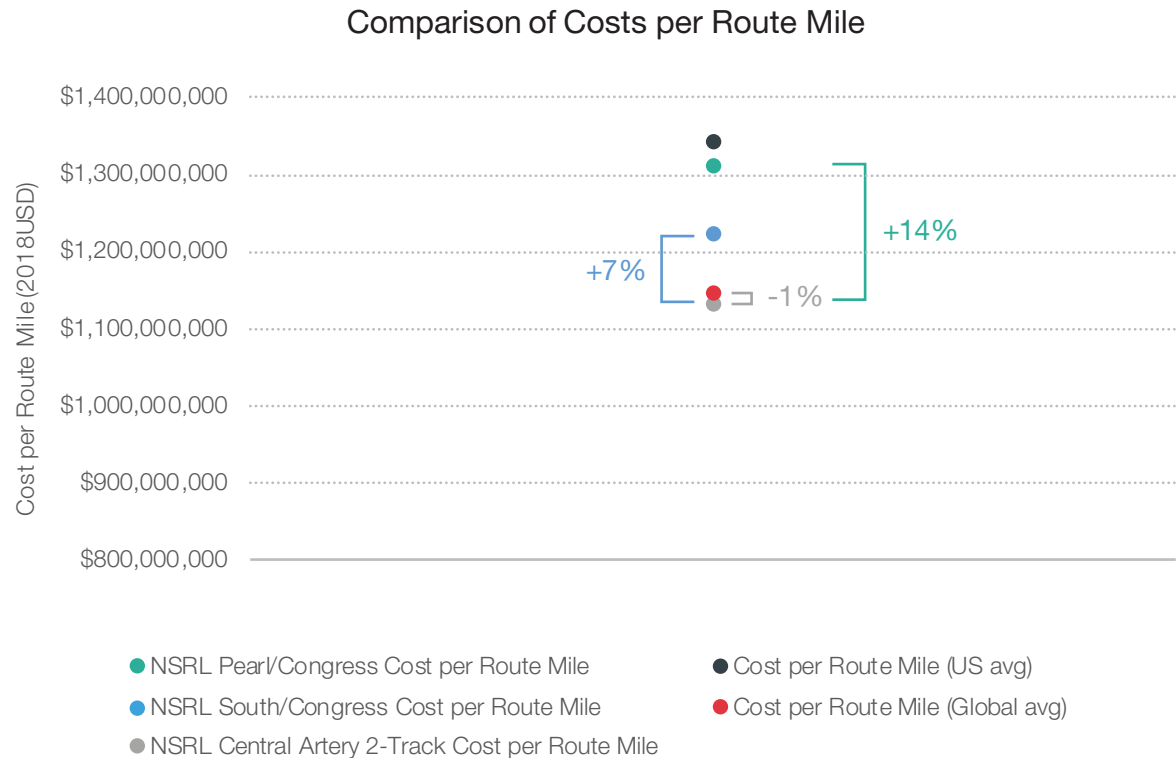


Figure E5: Comparison of Total Project Cost per Route Mile of Multiple Benchmarks Compared to NSRL Estimates (2018 USD).

Figure E5 shows how the NSRL Central Artery 2-Track Cost per route mile is 1% below the global average. The South/Congress cost per route mile is 7% above the global average due to its large diameter, and the Pearl/Congress cost per route mile is 14% above the global average due to the fact that all its stations are mined.

Project	Los Angeles Regional Connector	Los Angeles Purple Line Extension PH. 1	Los Angeles Purple Line Extension PH. 2	San Francisco Central Subway	NYC Second Ave. Subway Ph. 1	Leipzig City Tunnel	Zurich Durchmesserlinie	NSRL Central Artery 2-Track	NSRL South/Congress	NSRL Pearl/Congress
Alignment Length (miles)	1.9	3.92	2.59	1.7	2	3.3	6	5.40	5.49	5.77
Tunnel Diameter	22ft	19.10ft	19.10ft	19.8ft	22ft	29.4ft	36.7ft	41.5ft	51.5ft	29ft
Cost	\$1,744,000,000	\$3,114,000,000	\$2,525,000,000	\$1,578,000,000	\$4,450,000,000	\$1,030,000,000	\$2,000,000,000	\$6,117,156,950	\$6,729,692,200	\$7,585,932,000
Year	2014	2015	2018	2010	2017	2001	2001	2018	2018	2018
Location Factor (City or US Average)	112	112	112	124	102	97	106	N / A	N / A	N / A
Location Factor (Boston)*	115	115	115	115	115	115	115	N / A	N / A	N / A
Cost (Boston - 2018)	\$2,054,885,830	\$3,545,026,413	\$2,592,633,929	\$1,927,107,548	\$5,192,757,353	\$2,191,539,371	\$3,894,107,328	\$6,117,156,950	\$6,729,692,200	\$7,585,932,000
Cost per Route Mile	\$1,081,518,858	\$904,343,473	\$1,001,016,961	\$1,133,592,675	\$2,596,378,676	\$664,102,840	\$649,017,888	\$1,133,283,813	\$1,225,268,097	\$1,313,236,752

Table E9: Comparison of Total Project Cost per Route Mile of Multiple Benchmarks Compared to NSRL Estimates (2018 USD)

Location factors include material prices, labor rates, and all other market conditions inherent to each city. Boston is generally higher than most US cities, excluding San Francisco

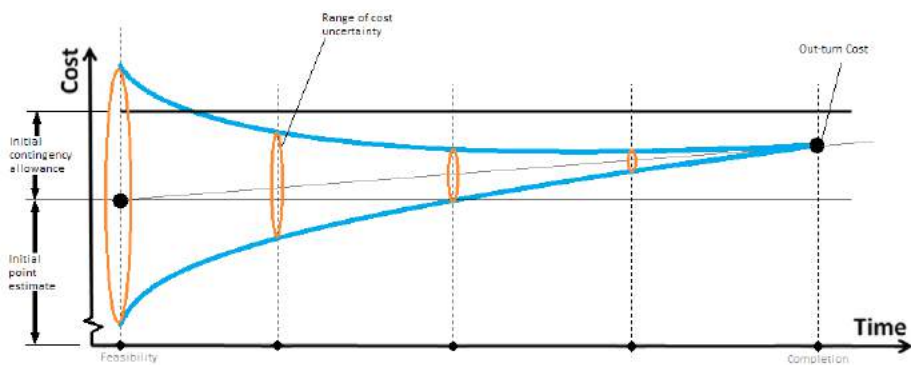


Figure E6: Evolution of Contingency Allowance and Estimate Over Time
 Source: Ian Gardner, *Achieving Successful Construction Projects: A Guide for Industry Leaders and Programme Managers* (New York, NY: Routledge, 2015), 96.

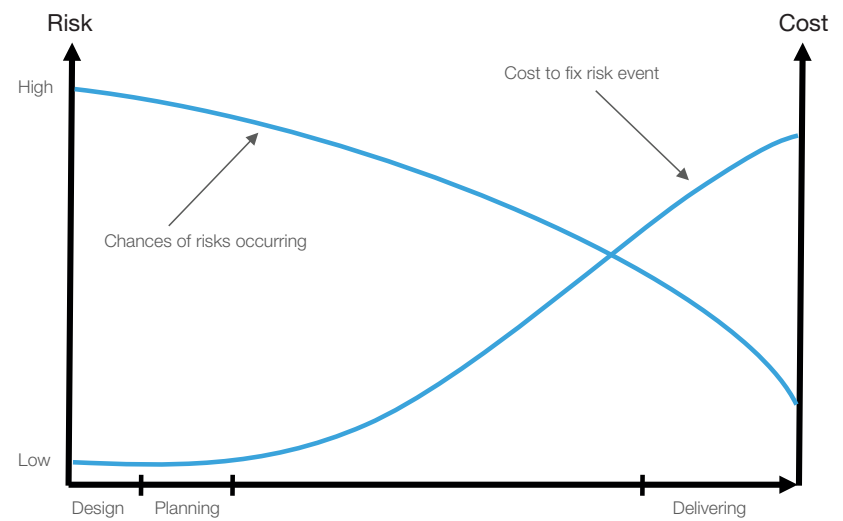


Figure E7: Evolution of Risk Occurrences and Costs
 Source: Ian Gardner, *Achieving Successful Construction Projects: A Guide for Industry Leaders and Programme Managers* (New York, NY: Routledge, 2015), 96.

Indirect Costs / General Conditions

- Indirect costs for the scope of work have been developed based on a typical build-up for similar construction projects. The included indirect cost categories are as follows:
- Mobilization – cost to establish a working construction activity at different jobsite locations; includes transportation of all equipment and labor to the site, establishment of requisite services, and commencement of construction activities
- Demobilization/punch list – cost for final closeout of the project, cleaning the facility, fixing and remedying any items not satisfactory, or finishing minor construction activities not directly affecting the project's substantial completion but required for final project closeout
- Contractor management staff – cost for management personnel, such as project managers, construction managers, and assistant project managers
- Additional staff – cost for the procurement manager, procurement staff, document controllers, office manager, schedulers, office engineers, and similar
- Field supervision staff and survey – cost for all site management above a project foreperson or shifter; included as project direct costs and include the general superintendent, project superintendent, assistant superintendent, engineer-

ing supervision, staff engineers, project controls, purchasing, warehouse, contractor quality assurance/controls, safety supervision, and survey

- Barges and tugboats for cofferdam works
- Automotive – cars, pickups, trucks, loaders, tractors, trailers
- Field office, office furniture, equipment, engineering supplies, and monthly utilities
- Small tools and supplies
- Health, safety, and sanitary costs
- Permits, bonds, and insurances

Different percentages were applied based on the complexity of the scope of work performed. All civil works have an indirect markup of 25% over the total direct costs. All tunneling works have an indirect cost markup of 40%. This difference is intended to account for the complexity of tunnel construction, which requires more on-site staff to survey and monitor the tunneling operations.

Additional Costs

- To estimate the total construction price, the following additional costs were added to direct and indirect construction costs:
- Contractor's contingency – assumed at 10% of total direct and indirect cost; what a contractor would price for uncertainty in quantities, labor rates, and other items outside of the scope they can control
- Contractor's overhead and profit – assumed at 12% of total construction cost, including design and estimate's contingency
- Design / engineering – assumed at 9% of the total construction cost, including contractor's overhead and profit; accounts for all design and engineering works to be performed by the entity designing and building the final project

Soft Costs

Soft costs are added on total estimated construction costs as a certain percentage in order to include additional scope of work to be completed for the project to be successfully delivered. The percentages used respond to industry standards for this type of project complexity and delivery. (The project is assumed to be completed via design-build, a project delivery method that implies contracting both the design and construction services to a single entity.) It is anticipated that this percentage may change as the project is further refined and stakeholder roles and involvement are assessed and agreed upon. A 15% markup for soft costs was applied over the total design-build price.

Soft costs include the following:

- Design quality assurance/controls and approvals process
- Agency project management and construction management support
- Quality assurance and quality control during construction, including inspections
- Environmental and other agencies' involvement
- Legal and other fees

Project Risk Contingency

Project risk management is the systematic process of planning for, identifying, analyzing, responding to, and monitoring project risk. Project risks are uncertain events or conditions that, should they occur, have a positive or negative impact on at least one of the project's objectives, such as time, cost, scope, or quality. As the project advances from the feasibility stages into preliminary engineering and design phases, a quantitative calculation of the risk contingency is performed as part of a Risk Management Plan. Risk contingencies would be then determined through a systematic approach of identification, assessment, and simulation through Monte Carlo analysis, a quantitative technique commonly used in project risk management.

The estimate includes a total project risk contingency (also referred to as Owner's contingency) applied to the construction price and soft costs. It accounts for procurement risks, contract administration, change order management, tunneling risk, political and economic risks, and others deemed relevant to the project. The risk contingency for the current Feasibility Reassessment has been applied based on recommended percentages and experience on other projects. Different factors for risk contingency have been applied to civil works (15%) and tunneling works (40%) to account for the higher risk potential in tunneling construction.

Escalation

To account for the value of money in time, and based on the rough total procurement duration for the project, the total cost of the project has been escalated from 2018 US dollars to midpoint of construction US dollars (estimated as 2028).

Tables E10 and E11 summarize the Construction Cost Index. Data were obtained from Engineering News Record (ENR) specifically for Boston and the average of the 20 major US cities. The Construction Cost Index is obtained by analyzing the changes in costs of labor and common construction materials. The average percent change for the national average is 3.37% per annum, and the average percent change for Boston is 4.06%. Based on these percentages, a rate of 3.5% per annum was included in the estimate.

$$\text{Escalation (E)}_{2028 \text{ MP}} = (1 + 3.5\%)^{10} - 1 = 41\%$$

Year	Avg. Base Points	% Change
2017	10,737	3.86%
2016	10,338	3.02%
2015	10,035	2.34%
2014	9,806	2.71%
2013	9,547	2.57%
2012	9,308	2.62%
2011	9,070	3.08%
2010	8,799	2.67%
2009	8,570	3.13%
2008	8,310	4.32%
2007	7,966	2.77%
2006	7,751	4.10%
2005	7,446	4.65%
2004	7,115	6.29%
2003	6,694	2.39%
2002	6,538	

Table E10: Construction Cost Index — National Average (2002–2017)

Source: ENR https://www.enr.com/economics/historical_indices/construction_cost_index_history

Year	Avg. Base Points	% Change
2018	14,234	3.44%
2017	13,761	3.54%
2016	13,290	5.77%
2015	12,566	1.22%
2014	12,414	1.11%
2013	12,279	2.09%
2012	12,027	4.15%
2011	11,548	3.69%
2010	11,136	4.13%
2009	10,695	4.63%
2008	10,221	5.05%
2007	9,730	5.02%
2006	9,264	6.68%
2005	8,685	5.53%
2004	8,230	3.18%
2003	7,976	5.69%
2002	7,547	

Table E11: Construction Cost Index — Boston (2002–2018 June)

Source: ENR https://www.enr.com/economics/historical_indices/Boston

The total construction duration for the South Station Expansion (No NSRL) alternative has been assumed as four years, with a construction/procurement start date in 2026 (this aligns the midpoint of construction to the schedule for the tunnel alternatives). The total construction/procurement duration for the tunnel alternatives is on average approximately eight years for all alignments, with a 2024 start date. The markup applied for escalation is as follows:

Tier 3 Costs

This section provides details on the Tier 3 costs referred to in Chapter 6.

Electrification

As part of the upstream/downstream improvements, electrification of the Lowell Line from West Medford Station to Lowell Station is identified as an option. Table E13 summarizes the total probable project costs for this discrete project component, at approximately \$498m (\$700m in 2028).

	South Station Expansion (No NSRL)	Central Artery 2-Track	South/Congress	Pearl/Congress	Central Artery 4-Track
Electrification of Lowell Line (route miles)	N / A	20	20	20	20
Electrification of Fairmount Line (route miles)	N / A	9	9	9	9

Table E12: Scope of Electrification

Table E13 summarizes the scope included in Tier 3 for the electrification works.

Electrification of the Fairmount Line from Readville into South Station is also identified as an option to assist in construction staging, allowing Amtrak access into South Station during construction at Back Bay. Table E14 summarizes the total probable project costs for this discrete project component, at approximately \$223m (\$314m in 2028).

Description	Total Cost (\$)
Lowell Line Electrification (route miles)	224,081,300
Total Direct Costs	224,081,300
Indirect Costs (25%)	56,020,400
Subtotal D + I	280,101,700
Contractor's Contingency (10%)	28,010,200
Subtotal	308,111,850
Overhead & Profit (12%)	36,973,500
Total Construction Costs	345,085,400
Design / Engineering (9%)	31,057,700
Total Design Build Price	376,143,100
Soft Costs (15%)	56,421,500
Subtotal Incl. Soft Costs	432,564,600
Project Risk Contingency (15%)	64,884,700
Total Project Costs Qtr. 1 2018 USD	497,449,300
Escalation to 2028 MP Construction (41%)	204,252,100
Total Cost Qtr. 1 2028 USD	701,701,400

Table E13: Summary of Costs for Lowell Line Electrification

Description	Total Cost (\$)
Fairmount Line Electrification (route miles)	100,350,000
Total Direct Costs	100,350,000
Indirect Costs (25%)	25,087,500
Subtotal D + I	125,437,500
Contractor's Contingency (10%)	12,543,800
Subtotal	137,981,300
Overhead & Profit (12%)	16,557,800
Total Construction Costs	154,359,100
Design / Engineering (9%)	13,908,600
Total Design Build Price	168,447,700
Soft Costs (15%)	25,267,200
Subtotal Incl. Soft Costs	193,714,900
Project Risk Contingency (15%)	29,057,300
Total Project Costs Qtr. 1 2018 USD	222,722,200
Escalation to 2028 MP Construction (41%)	91,470,000
Total Cost Qtr. 1 2028 USD	314,242,200

Table E14: Summary of Costs for Fairmount Line Electrification

Salem Tunnel Costs

Salem Tunnel costs include the tunneling works, retained cuts, trackwork, and allowances. Table E15 summarizes the total probable project costs for the Salem Tunnel, at approximately \$364m (\$513m in 2028).

The Tier 3 project cost estimate was performed with the following assumptions:

- Allowances have been made for all underpinning works identified for the tunnel alignments, including Salem Tunnel.
- Allowances based on square footage of retained cut have been made for all civil works associated with the portals and Salem Tunnel works.

Description	Salem Tunnel Costs (\$)
Tunneling Works	82,018,300
Other Excavation Works	29,534,800
Salem Tunnel Trackwork	7,796,100
Allowances	14,723,500
Total Direct Cost	134,072,700
Indirect Costs	45,821,000
Subtotal D + I	179,893,700
Contractor's Contingency (10%)	17,989,400
Subtotal	197,883,100
OH & P (12%)	23,746,000
Total Construction Costs	221,629,100
Design / Engineering (9%)	19,946,600
Total DB Price	241,575,800
Soft Costs (15%)	36,236,400
Subtotal incl. Soft Costs	277,812,200
Tunneling Risk (40%)	70,930,700
Civil Works Risk (25%)	15,072,800
Subtotal Risk Costs	86,003,500
Total Project Costs Qtr. 1 2018 USD	363,815,700
Escalation to 2028 (41%)	149,382,300
Total Project Costs Qtr. 1 2028 USD	513,198,000

Table E15: Summary of Costs for Salem Tunnel

F. Evaluation Weighting and Application of Scores

Evaluation Weighting

Weighting allows the owners and users to value some benefits (or impacts) of the projects differently than others, based on the Guiding Principles and their needs.

Each criterion is assigned a weighting factor based on these considerations; these range from 1 to 5, with 5 assigned the greatest importance. The following table provides guidance on the weighting for each criterion:

Importance of Criterion	Weight
Minor importance; Guiding Principles and owner/user goals will still be met if criterion is not or minimally achieved	1-3
Moderate importance; not critical to achieving Guiding Principles and owner/user goals, but clearly desirable to do so.	4-7
Extreme importance; vital to achieving Guiding Principles and owner/user goals; highly influential in gaining public support.	8-10

Table F1: Weighting Scale

Performance

A range of 1 (as a minimum) and up to 5 as a maximum) is assigned to the performance rank of each criterion. Most of these scores are relative to the other alternatives (for example, User Benefits of 100,000 hours per day, 150,000 hours per day, 200,000 hours per day, 250,000 hours per day, and 300,000 hours per day would be assigned scores

of 1, 2, 3, 4 and 5). Criteria are either objective and quantitative (which will be noted as calculations) or qualitative (which will be explained).

Scoring Methodology

A broad assignment of the weighting of each category is proposed as follows:

- Economy: 70%
- Environment: 15-30% (depending on whether 'Equity' scoring is present)
- Equity: 15-30% (depending on whether 'Environment' scoring is present)

In the scoring mechanics, a total possible score is 100 points. Economy is allotted up to 70 points, with Environment and Equity each having a possible 15-30 points (depending on the situation).

Scoring is performed at each screening level (Number of tracks, Construction Methodology, Alignment) and where the Economy Category is present with cost, it is always assigned 70% of the total score. When cost is present, it is always 50% within the 70%, resulting in cost always having up to 50% of the total score.

The economy scoring is as follows:

Criteria	Range	Weight	Total
Estimated Construction Cost	1-5	10	10-50
Total Commuter Rail Weekday Riders	1-5	4	4-20
User Benefit (Downtown Catchment Areas)	1-5	4	4-20
Risks – Permitting, Construction Risk, and Operations Risk	1-5	2	2-10
Potential for Phasing	1-5	2	2-10

Table F2: Economy Scoring

The environment scoring is as follows:

Criteria	Range	Weight	Total
Construction Impacts	1-5	2	2-10
Resilience in Disasters and Events	1-5	4	4-20
Increased Impacts of Commuter Rail Operations	1-5	2	2-10

Table F3: Environment Scoring

The equity scoring is as follows:

Criteria	Range	Weight	Total
Low-income households served	1-5	2	2-10
Low-income increases in ridership	1-5	2	2-10
Reduced crowding reductions on bus and rapid transit lines in low-income areas	1-5	4	4-20

Table F4: Equity Scoring

G. Environmental Evaluation and Permitting Summary

Introduction

As part of this NSRL Feasibility Reassessment, a Preliminary Environmental Evaluation and Permitting Summary has been completed. The goals of the preliminary environmental evaluation were specific to all proposed alignments (except the No Build) in order to:

- Identify the regulatory agencies that may have jurisdictional authority of cultural, historical, or natural resources that may be affected by this project
- Characterize the environmental conditions in the area of the NSRL project
- Identify sensitive resources and receptors
- Determine potential impacts to the design and proposed construction activities

As part of this preliminary evaluation, available sources for information on existing wetlands, floodplains, surface geology, protected and recreational open space, Areas of Critical Environmental Concern (ACECs), hazardous materials sites, air quality, greenhouse gas impacts, noise, cultural, historical and archaeological resources, and other constraints, were reviewed to analyze each alignment.

Proposed Project Alternatives

The alignments being considered included the construction of tunnels under the Charles River, the Fort Point Channel, the Red, Blue, Orange, Green, and Silver Lines, and the Central Artery. The evaluated alignments were as follows:

- Central Artery Two-Track – consists of one 41-foot-diameter tunnel
- Central Artery Four-Track – consists of two 41-foot-diameter tunnels
- South/Congress – consists of one 51-foot-diameter tunnel
- Pearl/Congress – consists of two 29-foot-diameter tunnels

The majority of the proposed project construction is below ground at depths between the surface and 150 feet below the surface. With the 51-foot-diameter tunnel alignments, stations can fit within the tunnel created by the boring. With the smaller bore alignments, the construction of stations would be completed separate from the tunnel bore via mining and/or cut-and-cover methods. Some of the evaluated alignments included construction of a station within the Fort Point Channel utilizing coffer dams. All alignments would require exhaust/air supply plants to properly ventilate the proposed tunnels and stations.

Evaluation of Environmental Impacts

A review of environmental resource databases and maps was conducted to develop an overall evaluation relative to the potential impacts of the project to environmental receptors and the public welfare. The evaluation addressed specific potential impacts in order to consider the need for developing mitigating measures. The figures in this Appendix depict the resources located generally within the project corridor.

Wetlands and Waterways

A review of the current MassGIS mapped wetland resource areas showed that the project would not be located within the buffer zone of bordering vegetated wetlands; and, as the project develops this would be verified. The project could result in temporary impacts to land under water and navigational channel width if the alignment is directed through the Fort Point Channel.

Air, Dust, and Noise

The proposed project would not include industrial processes that will release air contaminants to the atmosphere. The construction of the proposed project could result in the generation of exhaust during use of equipment with combustion engines; dust may also be generated during equipment staging and earthwork. No additional automobile traffic would be expected as a result of the project; therefore, automobile exhaust emissions would

be expected to remain as current conditions. It is assumed that additional trains would be running as a result of the project.

Construction noise would be generated during project work, as well as staging and support activities performed at grade level. Vibration could be anticipated as a result of earthwork, tunneling, and equipment staging and use. Construction noise and vibration mitigation measures could be required.

A detailed evaluation for greenhouse gas (GHG) emissions would be completed for the full environmental impact analysis. GHG emissions would likely increase as a result of the project, for any service alternative, from the addition of diesel train sets. It is anticipated that GHG impacts from the additional trains, however, would be at least partially offset by the commensurate reduction in automobile emissions from fewer vehicle trips.

Historical and Archaeological Resources

There are historic properties identified within the project corridor. Archaeological resources are also present within the corridor. Figures G3-G5 present historic and archaeological assets closest to each of the proposed new stations. In addition to consideration of historic and/or archaeological resources impacted by surface construction, a subsurface evaluation would also need to be completed to consider noise, vibration, and foundation impacts from both construction and operation of the corridor.

Endangered Species and Ecologically Sensitive Areas

The MassGIS maps for the Massachusetts Natural Heritage and Endangered Species Program (NHESP) and the online database provided for the U.S. Fish and Wildlife Service federally listed endangered species were reviewed. According to NHESP, there are no state-listed endangered species identified in the vicinity of this site. Also, there are no federally listed endangered species in the site vicinity. Also, according to MassGIS, the proposed project corridor is not located in a designated Area of Critical Environmental Concern.

Recreation and Open Space Resources

The project alignments do not appear to impact access to any existing open space or recreational area. Refer to Figure G9 for MassGIS delineation of Protected Open and Recreation Space.

Soil

The majority of all four proposed alignments are located within soils classified as Urban land, 0 to 15 percent slopes or Urban land, wet substratum, 0 to 3 percent slopes by the U.S. Soil Conservation Service, where soils have been altered or obscured by urban works or structures; areas where soil material has been excavated or deposited.¹ These are areas where 90 percent of the surface area is covered with impervious surfaces, such as

¹ Soil Survey of Suffolk County, Massachusetts

buildings, pavement, industrial parks, and railroad yards. The southern portion of the Central Artery Four-Track alignment and the northern portions of both Central Artery alignments would also pass through areas classified as Udothents, wet substratum.

For all proposed alignments, the project would generate a substantial amount of soil requiring management and off-site disposal or re-use.

Groundwater Resources

A portion of the project would be located above a medium-yield aquifer as shown on Figure G2. No part of the project alignments is located over a sole source aquifer or within the zone of influence of any public groundwater supply wells. Municipal water is available to the project area, and there are no public drinking water wells located within one mile. According to the City of Boston, there are no known private water or potable wells located along or near the project corridor. Current groundwater drinking water resources would not be impacted by the construction or operation of the proposed project.

Present stormwater drainage patterns in the immediate vicinity of the project would not be significantly affected. Stormwater is currently diverted from the alignment to existing drainage systems. Stormwater collected within the project area would continue to be directed into existing drainage systems if there is suitable capacity for the increased precipitation anticipated under current

climate change models. Stormwater that needs to be collected and managed for construction would be treated and discharged under a permit from the EPA's National Pollutant Discharge Elimination System (NPDES) program. An evaluation of additional stormwater management system capacity and requirements for the project would be developed during more detailed design.

Construction and operation of the proposed project is not expected to result in the introduction of any pollutants to groundwater. Appropriate temporary erosion controls and construction management procedures, including groundwater management would be developed as part of the project. Once constructed, water management would be limited to activities to prevent tunnel leaks and portal flooding.

Surface Water

The surface waters within the project corridor are shown on Figures G6-G8. The use of the Fort Point Channel for temporary or permanent structures would be evaluated during future design, which would also evaluate appropriate mitigation or protective environmental controls to prevent adverse impacts to these surface waters. With proper controls, construction and operation of the proposed project would not be expected to result in the introduction of any pollutants, including sediments, into marine waters or surface fresh waters.

Traffic

No additional automobile traffic is expected as a result of this project. Traffic impacts as a result of construction of this project could include travel lane restrictions or closures, reduced speed zones, and/or vehicle detours. These impacts would be temporary.

Solid Waste Management

Miscellaneous construction and demolition debris are expected to be generated as a result of the project. Construction waste would require management, transportation and disposal by a licensed contract hauler to an approved landfill. Future design must include an evaluation of the types and locations of one or more dedicated off-site facilities able to accept the materials generated.

Hazardous Materials

The proposed project, when constructed, is not expected to involve the use, generation, transportation, storage, release, or disposal of potentially hazardous materials. Quantities of wastes, including hazardous materials and contaminated soils, would likely be generated during demolition and removal of surface structures.

Sensitive Receptors

A project-specific analysis of potentially sensitive receptors was not conducted. Since most of the project would be deep below the ground

surface, sensitive receptors would be primarily those identified at tunnel entrances (portals) and/or open cuts within the Fort Point Channel. There are institutions (hospitals, schools, etc.) within 500 feet of the project corridor. The remainder of the surrounding area consists of dense commercial properties. Dust generated and noise impacts as a result of the project would need to be mitigated. Potential vibration impacts to cultural or historic structures or features would require advanced planning and follow-up monitoring. The appropriate traffic controls would be approved by MassDOT and implemented prior to the start of construction.

Potential Impacts to Design and Proposed Construction Activities

A preliminary mapping study has been completed to identify those areas that would need to be considered in the design development of the project. The areas evaluated are as follows:

FEMA Flood Hazard Zones

Approximately half of the Central Artery Two-Track alignment, the Central Artery Four-Track alignment, and the Pearl/Congress alignment and approximately one quarter of the South/Congress alignment are located within the FEMA Zone AE, 1% Annual Chance of Flooding with Base Flood Elevation (BFE). In addition, the existing North Station, the existing Aquarium Station, and the proposed Central Station in the Central Artery Four-Track alignment are all located in the FEMA

Zone AE. These Zone AE areas are located proximal to the Charles River, the Fort Point Channel, and Boston Inner Harbor. Another approximately one quarter of the Central Artery Four-Track alignment, located south of South Station and the Fort Point Channel, is located within the FEMA Zone X, 0.2% Annual Chance of Flooding.

Water Resource Areas

All four of the evaluated alignments would pass beneath the Charles River. Portions of the Central Artery Two-Track alignment, the Central Artery Four-Track alignment, and the Pearl/Congress alignment would be constructed beneath the Fort Point Channel, including the South Station expansions for both of the Central Artery alignments. Approximately 5% to 25% of each of the proposed alignments is located within the Boston Groundwater Conservation Overlay District (BGCOD) with the South/Congress alignment having the highest percentage of track within the BGCOD. A portion of the North Station expansion for both of the Central Artery alignments is located within the BGCOD and a portion of the South Station expansion for the South/Congress alignment is located within the BGCOD.

Historic Inventory & Landmarks

Dozens of Massachusetts Historical Commission (MHC) Historic Inventory Points are located within 500 feet of the proposed alignments. MHC Historic Inventory Points are most densely located along the

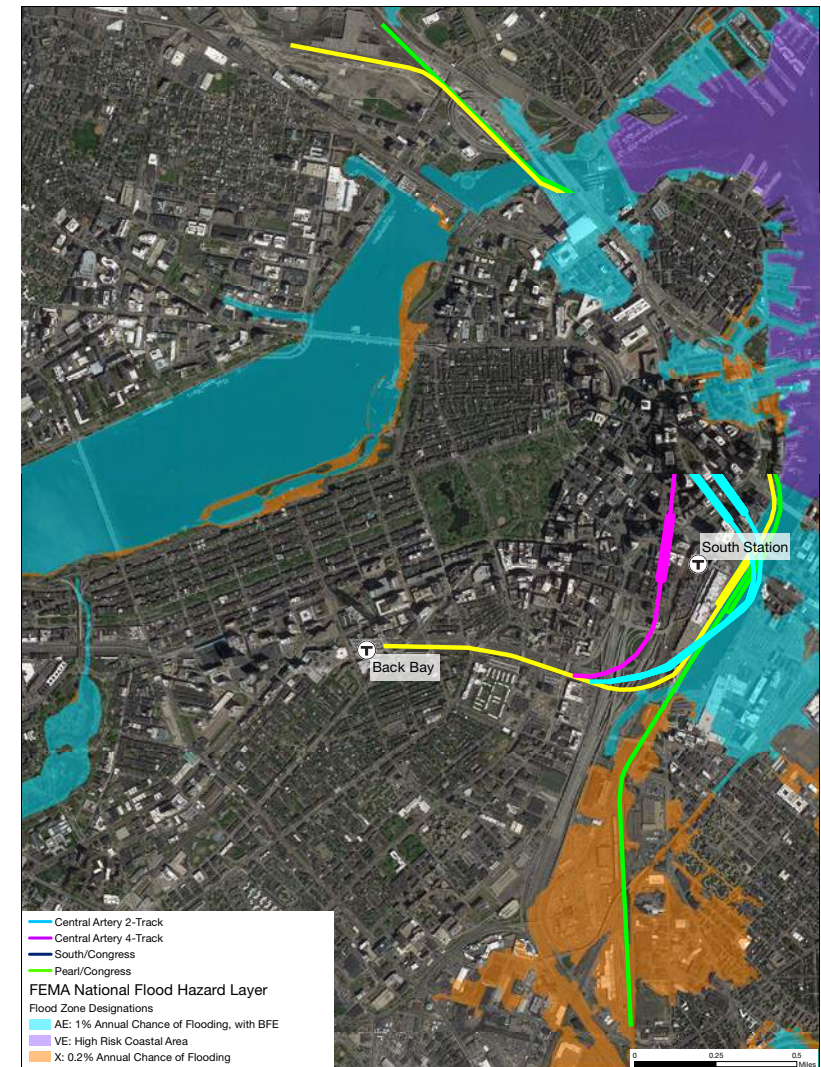


Figure G1: FEMA Flood Hazard Zones

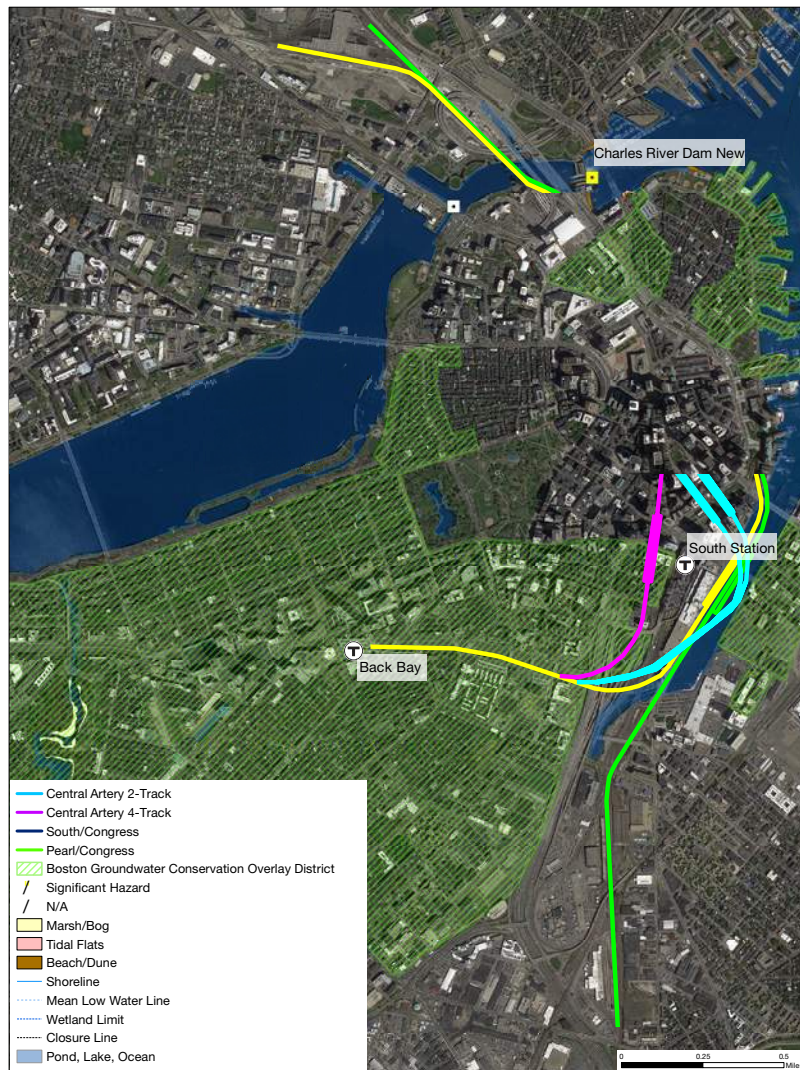


Figure G2: Water Resource Areas

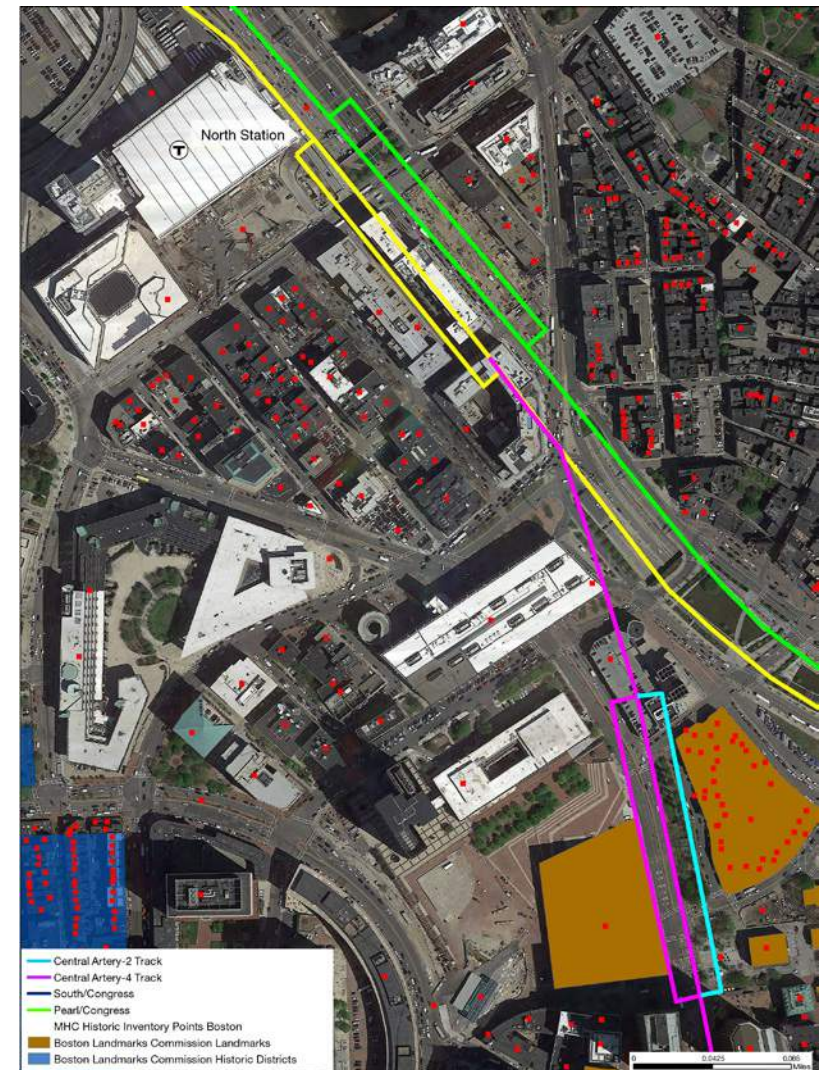


Figure G3: Historic Inventory at North Station



Figure G4: Historic Inventory at Central Station

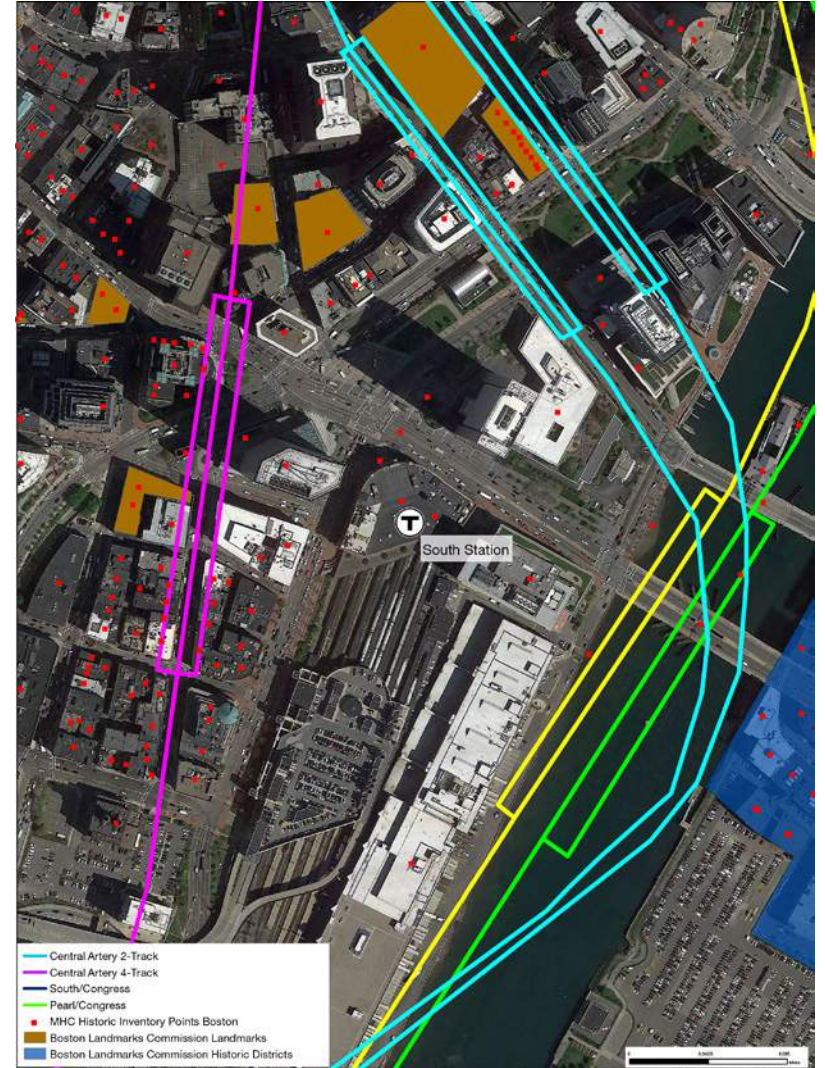


Figure G5: Historic Inventory at South Station

alignments between the current South and North Stations. Portions of the proposed South Station expansion for the South/Congress and Pearl/Congress alignments are located beneath Boston Landmarks Commission Landmarks. Portions of all four proposed alignments to the south of the current South Station also pass beneath a Boston Landmarks Commission Historic District.

Sea Level Rise Predictions

In 2016, the City of Boston completed an assessment of future climate change projections and impacts, including projections for sea level rise, precipitation and temperature. The study, *Climate Ready Boston*, identified three sea level rise scenarios for the City: near-term (2030s-2050s), mid-term (2050s-2100s), and later-term (2070s onwards).² Figures G6-G8 detail the projected future flood impacts during the average monthly high tide, the 10% annual chance flood, and the 1% annual chance flood, based on these three sea level rise scenarios. The greatest potential impact to the project from future coastal flooding is based on the locations of the portals and the stations; the potential impact to the tunnels is less of a concern.

The Average Monthly High Tide (with nine inches of sea level rise in the 2030s) appears to be fairly similar to the limits of existing 2018 surface water bodies, with a slight expansion of the tides along the north bank of the Fort Point Channel at the

Pearl/Congress alignment. The 10% Annual Flood (with nine inches of sea level rise in the 2030s) is predicted to impact the proposed Central Station/existing Aquarium Station as well as the current North Station for both the Central Artery Two-Track and Four-Track alignments. Aquarium Station is one of the most vulnerable rapid transit stations in the existing MBTA system and has previously flooded during past storm events. The 1% Annual Flood (with nine inches of sea level rise in the 2030s) is predicted to impact the proposed Central Station/existing Aquarium Station and the current North Station for both the Central Artery alignments, a portion of the proposed underground North Station for the Central Artery alignments, and a portion of the proposed State/Haymarket Station for the South/Congress alignment.

The Average Monthly High Tide (with 21 inches of sea level rise in the 2050s) appears to be fairly similar to the limits of existing 2018 surface water bodies, with a slight expansion of the tides along the north bank of the Fort Point Channel at the Pearl/Congress alignment and near the existing Aquarium Station. This may result in impacts to the proposed Central Station for the Central Artery alignments. The 10% Annual Flood (with 21 inches of sea level rise in the 2050s) is predicted to impact the proposed Central Station, the current North Station, a portion of the proposed underground North Station, and the portion of the Central Artery Four-Track alignment located south of the Fort Point Channel. The 1% Annual Flood (with 21 inches of

sea level rise in the 2050s) is predicted to impact the proposed Central Station, the current North Station, a portion of the proposed underground North Station, a portion of the proposed State/Haymarket Station for both the South/Congress and Pearl/Congress alignments, a portion of the proposed South Station expansion for the South/Congress alignment, and a portion of all four alignments located south of the current South Station.

The Average Monthly High Tide (with 36 inches of sea level rise in the 2070s) expands along the north bank of the Fort Point Channel at the Pearl/Congress alignment, into a portion of the proposed State/Haymarket Station, into a portion of the proposed Central Station, and into both Central Artery alignments surrounding the proposed Central Station. The 10% Annual Flood (with 36 inches of sea level rise in the 2070s) is predicted to impact the proposed Central Station, the current North Station, a portion of the proposed underground North Station, a portion of the proposed South Station expansion for the South/Congress alignment, a portion of the proposed State/Haymarket Station, a portion of the tracks surrounding the existing North Station and proposed underground North Station, a portion of the tracks surrounding the existing Aquarium Station/proposed Central Station, and a portion of all four alignments located south of the current South Station. The 1% Annual Flood (with 36 inches of sea level rise in the 2070s) is predicted to impact the proposed Central

² *Climate Ready Boston*, 2016.

Station, the current North and South Stations, a portion of the proposed underground North Station, a portion of the proposed State/Haymarket Station, and a portion of the proposed South Stations for the South/Congress and Pearl/Congress alignments.

Additionally, flood impacts are predicted to affect the tracks surrounding the current North Station and proposed underground North Station, the tracks surrounding the current Aquarium Station/proposed Central Station, the tracks of all four alignments south of South Station, and a portion of the South/Congress and Pearl/Congress tracks surrounding the proposed State/Haymarket Station.

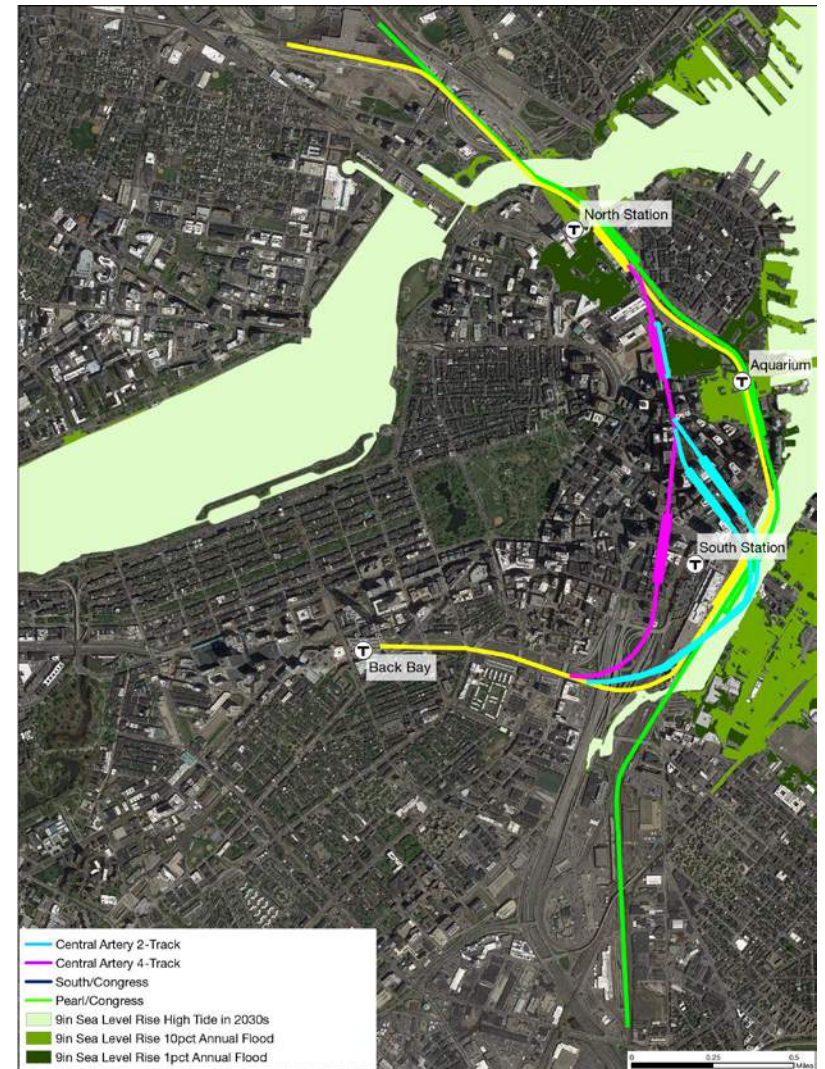


Figure G6: 2030s 9 Inch Sea Level Rise Projection

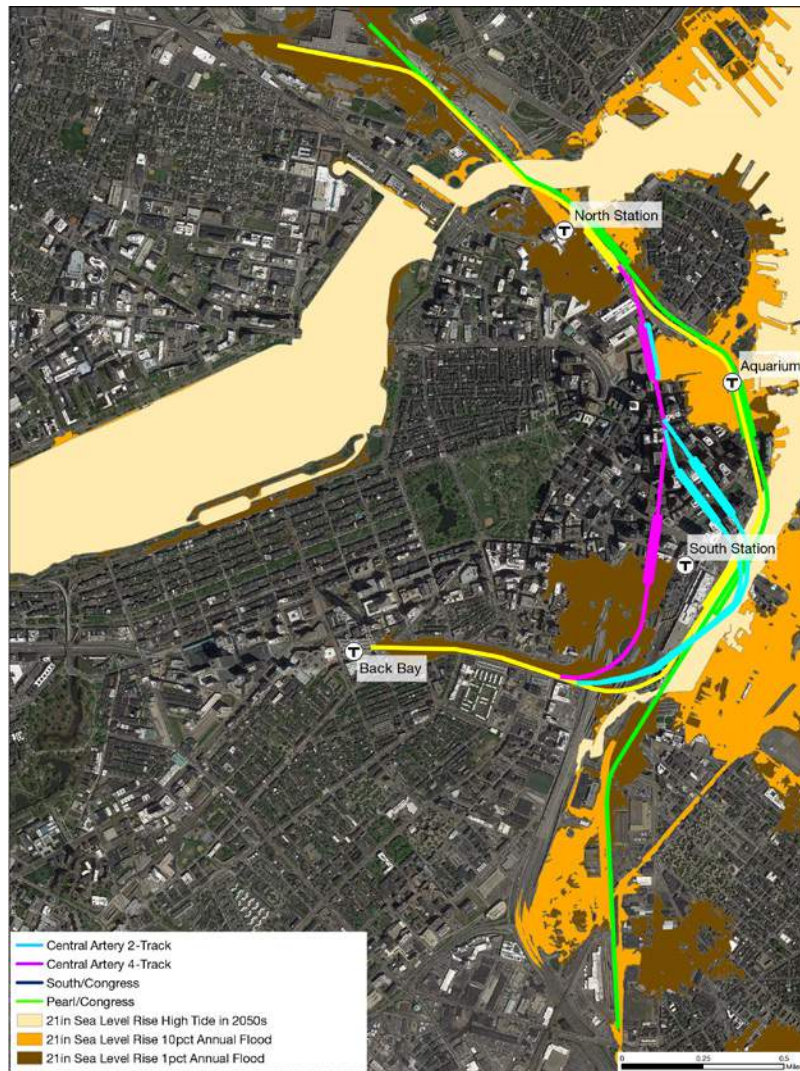


Figure G7: 2050s 21 Inch Sea Level Rise Projection

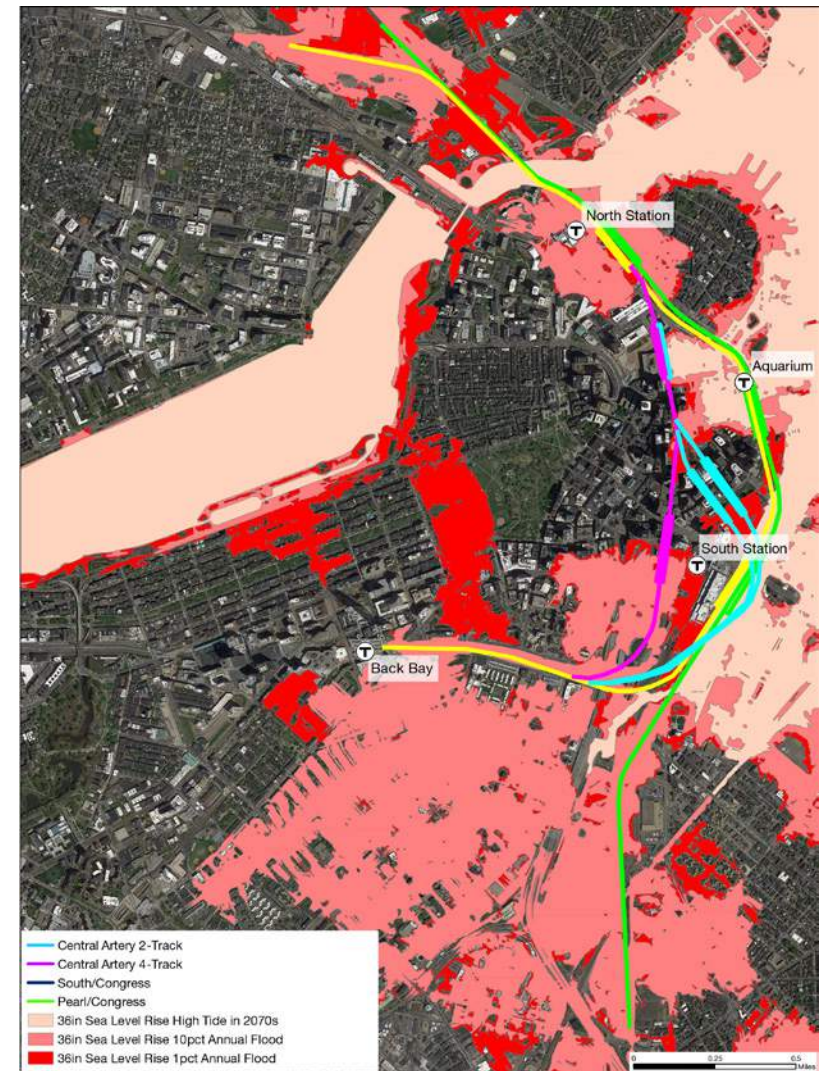


Figure G8: 2070s 36 Inch Sea Level Rise Projection

Open Space

Approximately 5% to 25% of each of the proposed alignments is located beneath areas designated as Boston Open Space – Malls, Squares, and Plazas. Nearly all of these areas are located between the current North and South Stations. The Central Artery alignments have the highest percentage of track within areas designated as Boston Open Space. Cut-and-cover portal locations would require a more detailed analysis of potential impacts to designated open space.

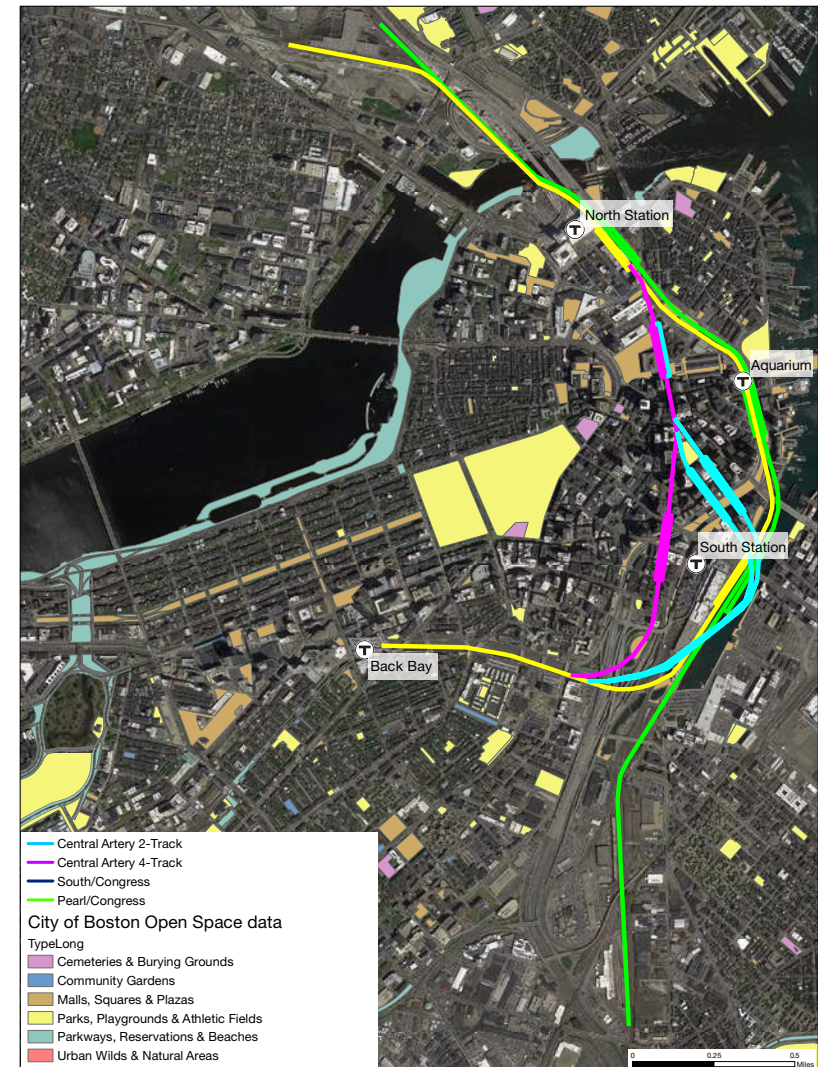


Figure G9: Open Spaces

Preliminary Project Permits and Approvals

With the exception of the No Build, construction of the project alignments would require environmental permits, approvals, and notifications and strategic coordination between multiple state and federal agencies. This is only a preliminary assessment of the approvals needed to advance the project. In addition, as the project design reaches its final stages, it could be determined that certain permits and approvals described are not necessary. Based on the feasibility study parameters and assumptions, the following agencies and related regulations, bylaws, and relevant resources were considered applicable:

Federal Agencies

The following are the federal agencies likely holding jurisdiction over the project:

- National Environmental Policy Act (NEPA)
- U.S. Coast Guard (USCG)
- U.S. Army Corps of Engineers (ACOE)
- U.S. Fish and Wildlife Service (USF&W)
- National Historic Preservation Act (NHPA)
- U.S. Environmental Protection Agency (EPA)

National Environmental Policy Act (NEPA)

It is anticipated that the proposed project will utilize federal funds. NEPA's basic policy is to assure that all branches of government give

proper consideration to the environment prior to undertaking any major federal action that could significantly affect the environment. At a minimum, the project would require preparing a Categorical Exclusion (CE) Checklist for Federal-Aid Actions. An Environmental Assessment (EA), an Environmental Impact Statement (EIS), or both may also be required. Further environmental analysis would be dictated by the project scale and the lead federal agency. These studies would also document potential mitigation and off-setting benefits over the potential impacts. The previous environmental review process for the NSRL project, conducted in 2003, is now significantly outdated and the recommended alignment has changed; therefore, an updated federal environmental review process will likely be required in order for the project to be eligible for federal funding or loan guarantees.

U.S. Coast Guard

Any permanent construction that would change the horizontal or vertical clearance of navigable waters under the jurisdiction of the USCG would require a Section 9 permit. This would be applicable for any alignment that would permanently interfere with navigation in the Fort Point Channel.

U.S. Army Corps of Engineers

The ACOE carries jurisdiction in the civil works projects centered around navigation, flood control, and under the Water Resources Development Acts. Also, the ACOE regulates dredging or filling that

may alter the embankment at/or below the high-water mark within ACOE jurisdictional waterways. Such work would require a permit under Section 404 of the Clean Water Act (CWA). This project could also fall under the jurisdiction of more intensive permitting with the ACOE due to potential dredging and/or filling of the Fort Point Channel.

U.S. Fish and Wildlife Service

The USF&W, under Section 7(c) of the Endangered Species Act (16 USC 1533) and Section 2 of the Fish & Wildlife Coordination Act (16 USC 661) maintain jurisdiction over designated areas subject to the protection of threatened or endangered species. Coordination and possibly mitigation would be required if threatened or endangered species are identified within the project corridor or in the project area.

National Historic Preservation Act (NHPA)

Section 106 of the NHPA requires Federal agencies to consider the effects of federally funded projects on historic properties and to afford the Advisory Council on Historic Preservation an opportunity to comment on such projects prior to the expenditure of any federal funds. The Massachusetts Historical Commission, the State Historic Preservation Officer (SHPO), coordinates the state's historic program and consults with federal agencies during the Section 106 review. The intent of the Section 106 review is to both determine what the potential adverse effects may be; and where possible,

mitigate the potential of adverse effects. Several historic sites are identified within the project corridor; therefore, further analysis would be required to determine potential impacts.

U.S. EPA

The EPA issues stormwater general permits under the Clean Water Act (CWA) for discharge of stormwater runoff from construction sites. Such permits, which are issued by the EPA's National Pollutant Discharge Elimination System (NPDES) program, would be required for construction activity which disturbs one or more acres of land surface. If dewatering with discharge to a navigable waterway of contaminated groundwater is required during the Project, authorization under the NPDES Remediation General Permit (RGP) may also be required for the project.

The EPA regulates the generation, handling, management, treatment, and disposal of hazardous wastes under the Resource Conservation and Recovery Act (RCRA). If storage or generation of hazardous waste is anticipated under this project, including the disposal of hazardous material as a result of demolition of structures, a RCRA permit could be required. If the project involves the generation of polychlorinated biphenyl (PCB) wastes, including PCB contaminated soil, the Project would have to meet requirements for storage and disposal of PCB waste under the Toxics Substances Control Act (TSCA) which is regulated by the EPA. If oil and/or hazardous materials are

released or encountered during construction, the project would be subject to requirements under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) which is administered by the Massachusetts DEP under the MGL c21E program.

The Clean Air Act (CAA) Requirements for mobile and stationary sources impacting air which apply to construction activities are implemented primarily through State Implementation Plans (SIPs) which are approved by the EPA. The relevant requirements of the Massachusetts SIP are discussed in the following section.

State Agencies

The following are the state agencies likely holding jurisdiction over the project:

- Massachusetts Executive Office of Environmental Affairs
- Massachusetts Office of Coastal Zone Management (CZM)
- Massachusetts Department of Environmental Protection (MassDEP)
- Massachusetts Historical Commission (MHC)
- Massachusetts Water Resources Authority (MWRA)
- Massachusetts Division of Fisheries and Wildlife (MassWildlife)

Massachusetts Executive Office of Environmental Affairs

The Commonwealth of Massachusetts Executive Office of Environmental Affairs established the Massachusetts Environmental Policy Act (MEPA) regulations, which set criteria for the threshold permit and submittal requirements for proposed projects that may have environmental impacts upon the Commonwealth and require a state permit. The Act requires that agencies use all feasible means and measures to avoid or minimize damage to the environment. MEPA thresholds would be reviewed to determine whether this project requires the filing of an Environmental Notification Form (ENF)/ Environmental Impact Report (EIR) requirements. The previous environmental review process for the NSRL project, conducted in 2003, is now significantly outdated and the recommended alignment has changed; therefore, an updated state environmental review process and DEIR will likely be required under state law.

Also under MEPA, the project would be evaluated for historic impacts, and may require a Determination of No Adverse Effect or mitigation negotiated within a Memorandum of Agreement with the Massachusetts Historical Commission. MEPA is a parallel review with NEPA and provides the framework under Massachusetts Law within which the environmental impacts of a proposed action must be evaluated. The MEPA program permits coordination of MEPA requirements with

NEPA documents. MEPA makes clear that Draft and Final Environmental Impact Statements (EISs) under NEPA may be submitted in lieu of an Environmental Impact Report (EIR), provided that the NEPA documents comply with applicable State requirements and policies.

Massachusetts Office of Coastal Zone Management

The CZM was established to implement the Commonwealth's coastal zone management plan in response to the federal Coastal Zone Management Act. Under the Massachusetts Coastal Zone Management Program Federal Consistency Review Procedures (301 CMR 21.00), CZM is given the authority to implement the federal consistency review of any project requiring a federal action to ensure that the project is consistent with the Commonwealth's coastal zone program policies. CZM looks to established environmental review thresholds to gauge when projects significantly impact the coastal zone and cooperates with federal agencies to develop general permits for projects of minimal environmental impact. Depending upon the selected alignment, the NSRL project could require a consistency review if it is within CZM jurisdiction.

Massachusetts Department of Environmental Protection

The project team reviewed the requirements of the various MassDEP divisions as they may relate to this project.

Bureau of Resource Protection – Wetlands Protection Act (WPA, 310 CMR 10.00)

In accordance with MassDEP Wetlands Protection Act (WPA), which regulates designated resource areas, MassDOT would file a Notice of Intent (NOI) at the local level for review and file a copy with MassDEP. A filing would be made to the Boston Conservation Commission and, if appropriate, the Cambridge Conservation Commission.

Waterways (310 CMR 9.00)

If cofferdams, barges or other temporary structures will be required for the work within the Fort Point Channel, filings could be required with Waterways Division. The installation of temporary or permanent obstructions in the channel will require Department review with or without federal agency coordination. As the project design becomes more advanced a multi-agency meeting would be coordinated to discuss the jurisdiction and approvals needed for temporary or permanent impacts to the Fort Point Channel.

Water Pollution Control, 401 Water Quality Certificate (314 CMR 9.00)

If the selected option includes work within the Fort Point Channel (dredging and/or filling), it is estimated that there will be greater than 5,000 square feet of disturbed land under water, and over 100 cubic yards of displaced sediment; therefore, a 401 Water Quality Certification would be required. Individual project requirements, including sediment

testing, to secure the Water Quality Certificate would depend upon the extent of potential impact.

Air Pollution Control for Mobile Sources, (310 CMR 60.00)

The purpose of 310 CMR 60.00 is to implement §176(c) of the Clean Air Act, with respect to the conformity of transportation plans, programs and projects which are developed, funded or approved by the U.S. Department of Transportation, and by metropolitan planning organizations or other recipients of funds. or the Federal Transit Act. The regulation sets forth policy, criteria and procedures for demonstrating and assuring conformity of such activities to the Massachusetts State Implementation Plan. This includes accounting for the air quality impacts of large transportation projects within the long range regional transportation plans (RTPs) of the Commonwealth's metropolitan planning organizations (MPOs).

Massachusetts is currently required to perform a transportation conformity determination on any new RTP and transportation improvement program (TIP), updates, and amendments that include the addition of a project that is not exempt (also known as a regionally significant project) from transportation conformity. As a regionally significant project, NSRL would need to be included in the Boston MPO's transportation model in future milestone years, which produce aggregated estimates of changes to ozone precursor pollutants based on the inclusion of all the non-exempt projects. The results would

then be combined with all the other MPOs in the Eastern Massachusetts Ozone Non-Attainment Area to demonstrate air quality conformity of the latest RTP and TIP.

Massachusetts Historical Commission (MHC)

This project would be subject to the applicable requirements of the National Historic Preservation Act, administered by the MHC as the SHPO, as described previously.

Massachusetts Water Resources Authority (MWRA)

In accordance with M.G.L. Ch. 372 Acts, 1984, Section 8, any work performed within a MWRA easement requires an 8(m) Permit. Contractors would be responsible for submitting the 8(m) Permit application to the MWRA.

Massachusetts Division of Fisheries and Wildlife (MassWildlife)

MassWildlife is responsible for the conservation, restoration, protection and management of fish and wildlife resources for the benefit and enjoyment of the public. Also, MassWildlife is responsible for enforcing the Massachusetts Endangered Species Act (MESA). This Project is exempt from MESA consultation since, based on Massachusetts Bureau of Geographic Information (MassGIS) mapping, it appears that there are currently no Estimated Habitats for Rare Wildlife or Priority Habitats for Rare Species, no Certified or Proposed Vernal

Pools, and no Areas of Critical Environmental Concern within the project corridor.

Local Agencies

The local environmental permitting requirements include filing a Notice of Intent with the local Conservation Commission in Boston in accordance with the MassDEP Wetlands Protection Act (310 CMR 10.00). There are no other local environmental permits required for this project; also, MassDOT is exempt from local bylaws. However, there could be permit requirements for construction that are not related to environmental permitting.

The Boston Planning and Development Agency (BPDA) oversees proposed projects within the Boston Groundwater Conservation Overlay District (BGCOD) under Article 32. Any applicant seeking a building permit for a proposed project within a Groundwater Conservation Overlay District is subject to the requirements of Article 32 where such applicant seeks:

- The erection or extension of any structure, where such new structure or extension will occupy more than fifty (50) square feet of lot area
- The erection or extension of any structure designed or used for human occupancy or access, mechanical equipment, or laundry or storage facilities, including garage space, if such construction involves the excavation below grade to a depth equal to or below seven (7) feet above Boston City Base (other than where such excava-

tion is necessary for, and to the extent limited to, compliance with the requirements of Article 32)

- To substantially rehabilitate any structure
- Any paving or other surfacing of lot area

In addition to complying with the BPDA's Article 32, Boston Water and Sewer Commission (BWSC) reviews plans for projects within the BGCOD to verify that projects include a suitably-designed infiltration system equivalent to no less than 1.0 inches across the portion of the surface area of the lot occupied by the proposed project. The project proponent would be required to obtain a license from the Public Improvement Commission if the infiltration system proposed is located under the public rights-of-way (sidewalk or roadway).

H. Public Engagement

This Appendix summarizes the public engagement that has been conducted on this Feasibility Reassessment – primarily through public meetings focused on different areas of the project and a comment period for the draft final report, posted online.

Public Meetings

Three public meetings were held over the course of this Feasibility Reassessment. MassDOT staff gave detailed presentations, experts were on hand to explain various aspects of the project, and attendees from the public were allocated time for comment.

- The first public meeting was held on October 17, 2017. The main focus of this meeting was to explain the history of the NSRL concept, the scope, objectives and timeline for this Feasibility Reassessment, and lay out next steps for the project.
- The second public meeting was held on June 21, 2018. This meeting introduced the public to the proposed service plans and tunnel alignments, including locations for tunnel portals and stations. The meeting also provided ridership and cost estimates, based on the work completed so far.
- A third and final public meeting was held on December 10, 2018. This meeting concluded the Feasibility Reassessment process, providing a summary and responses to general public comments received, presenting detailed cost methodology to back up the costs presented at

the second public meeting, and revealing the proposed preferred alignment from the four presented at the second public meeting. The proposed alignment is intended to inform MassDOT's future decision-making through the normal project development process.

Comments on the Project

The first seven chapters of the draft final report were posted on MassDOT's website in September of 2018. A draft Chapter 8 and Appendix F (detailing the preferred alignment) were posted online in early December of 2018. These chapters were open for public comment through December 21st, 2018. In total, comments from 79 people (including from Amtrak, three organizations and three elected officials) were received on the draft report and have been considered in the final version of the report.

All public meeting and report materials are available on MassDOT's website at the following link: <https://www.mass.gov/lists/north-south-rail-link-feasibility-reassessment-study-documents>

